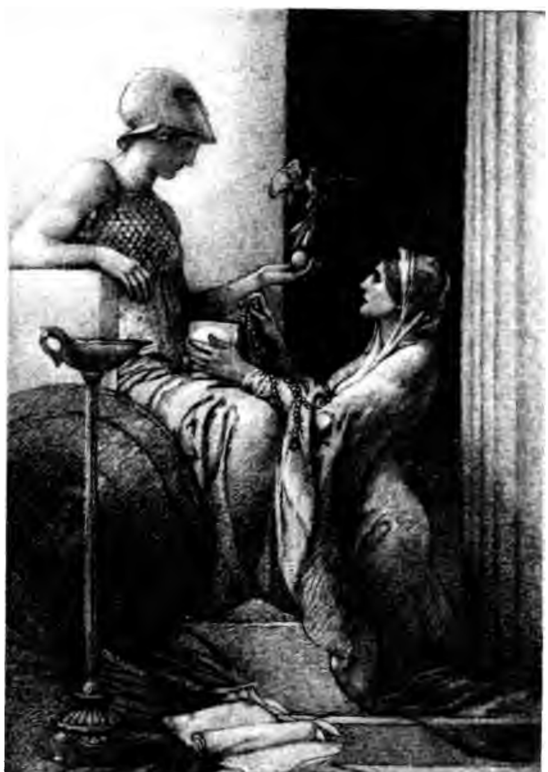

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 25

THE PRESENT TECHNICAL CONDITION OF THE STEEL INDUSTRY OF THE UNITED STATES

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

ADVERTISEMENT.

The following are in press, viz:

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. ix, 338 pp. 35 pl.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. —, — pp. 56 pl.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl.

The following are in preparation, viz:

I. The Precious Metals, by Clarence King.

— Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons.

— Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

— Lake Bonneville, by G. K. Gilbert.

— Sauropoda, by Prof. O. C. Marsh.

— Stegosauria, by Prof. O. C. Marsh.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper, and will be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this, each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 25 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining value of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. A Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Dr. C. A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the higher Devonian Faunas of Ontario County, New York, by J. M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.

17. On the Development of Crystallization, etc., by Arnold Hague and J. P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Dr. C. A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White, M. D. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

ADVERTISEMENT.

23. The Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary Fossils and recent forms, from American localities between Cape Hatteras and Cape Roque, including the Bermudas, by W. H. Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 82 pp. Price 10 cents.

Numbers 1 to 6 of the Bulletins form Volume I; Numbers 7 to 14, Volume II; and Numbers 15 to 23, Volume III. Volume IV is not yet complete.

The following is in press, viz:

26. Copper Smelting, by H. M. Howe. 1885. 8°. 107 pp. Price 15 cents.

STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, has been undertaken. Of that series the following have been published, viz:

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Correspondence relating to the publications of the Survey, and all remittances, which must be by POSTAL NOTE OR MONEY ORDER, should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C.

WASHINGTON, D. C., *September* 5, 1885.

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 25

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

THE PRESENT TECHNICAL CONDITION

OF THE

STEEL INDUSTRY

OF THE

UNITED STATES

BY

PHINEAS BARNES

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

CONTENTS.

LETTER OF TRANSMITTAL.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF MINING STATISTICS,
Washington, D. C., July 25, 1885.

SIR: I have the honor to transmit herewith a paper by Mr. Phineas Barnes on The Present Technical Condition of the Steel Industry of the United States. This paper is supplementary to the report of this division entitled "Mineral Resources of the United States, 1883 and 1884." Mr. Barnes, in this essay, gives a general view of existing conditions and practice, which is of special interest at the present moment in view of the rapidly advancing strides made by the important industry under discussion.

Very respectfully, your obedient servant,

ALBERT WILLIAMS, JR.,
Geologist in Charge.

Hon. J. W. POWELL,
Director United States Geological Survey.

THE PRESENT TECHNICAL CONDITION OF THE STEEL INDUSTRY OF THE UNITED STATES.

By PHINEAS BARNES.

INTRODUCTORY.

Any general statements concerning the technology of the steel industry of the United States should comprise a description of the raw materials, including fuels, which are used in connection with it; the processes of manufacture to which these materials are subjected, including the machinery and apparatus; and also the uses for which the metal is employed, including the tests by which its fitness for these purposes is determined and actually measured. Such general statements if extended sufficiently to cover only an approximate detail would necessarily be lengthy, and at best could do only scant justice to the painstaking labor and study which have been expended upon the development of the manufacture of steel at every stage of its progress and during many years past. It is needful therefore in this paper that the simplest outlines only of the whole advance in this department of metallurgy should be sketched, and that the endless detail, however important, of the remote past should be neglected in favor of the costly efforts to promote the art at the present day by a reduction of the cost of manufacture and the widening of the fields of the actual use of the metal. It should also be clearly understood that wide differences exist, some being apparently irreconcilable, between men of extended and trustworthy experience, in respect to materials, methods, and tests of finished product. Hence any brief description must be confined in large part to the useful details upon which agreement is general, and must seek to indicate the limits, more or less wide, between which these opposing views are held. In the important matter of analyses of materials, at various degrees of advancement, no general attempt can be made to strike an average of a series that shall be useful as compared with the statement of one or more analyses which shall present, either singly or in comparison, the current determination in actual business of some analyst of trustworthy reputation. It should be remembered that the managers or the melters of steel works are governed in their use of their materials not alone by the apparent indication of this or that analysis, but also by the preference which may for the moment be based

upon some current price, or the quantity of material in their stock. The minute detail of their practice may also turn upon the special good or bad working of their furnaces, or some other even more trifling thing, which may possibly be felt rather than seen and hence be nearly or quite impossible of detection by any kind of analysis or test whatever. Thus arises the extreme difficulty, in any discussion or description, of saying many things which shall be useful or conclusive, as the significance and value of any statement must lie in the application of the facts at issue by the man who alone can know, and who must know, the entire detail.

An important question arises at the first step of the inquiry as to the definition that shall be given to the time-honored term "steel." This springs from the fact that additional kinds or qualities of metal, all more or less steely in their nature, have been developed at a comparatively recent day in the practice of steel melters in the use of their older forms of furnaces, although at the present moment other and more suitable fixtures have been adapted to the production of these newer varieties or grades of the parent metal. It has been found that important and delicate technical and commercial disputes will be likely for a long time to turn upon the exact meaning which shall be assigned to the simple word "steel," and hence little more need be attempted by way of definition than to state in general terms the basis of the differences between those forms of the metal as derived from the prime element, iron. From such starting point as this each purchaser can indicate, and usually does, his exact requirement of quality.

Steel in the older sense of the term meant a metal which would harden or temper, and for a long space of time this grade or quality of the metal alone was the current and quoted product of steel-melters' furnaces. At length it was found, largely by accident in many hands, that a metal was sometimes made, and, after a time, that it could be produced regularly, which, though it could not be hardened by the usual methods, proved to be very high in absolute tensile strength, extremely uniform in its crystalline structure, and ductile or malleable to an unexpected degree. In short, iron had been made by a new method, which, if it was not "iron in its best form," was nevertheless iron in a form which had not previously been known in actual practice in the metal world. This proved, almost from the first, to be a means of relief from numerous difficulties which had long been felt in the most skillful use of nearly every grade or quality of iron as it had previously been made.

Prolonged discussion among men who have studied the situation seems to show that, on the whole, it is preferable that all those forms or grades of metal which have been melted, or have taken on their final molecular structure after passing through a fusion process, whatever may have been the method employed, and which are malleable in the usual sense of the word and at proper temperatures, should be known and classed as "steel," without reference to the possibility of hardening or tempering. For obvious reasons any acceptance and use of this

definition does not insure that a purchaser shall obtain in any market by calling for "steel" just the kind or grade that he may require, without giving the steel melter either an exact specification of quality, or a description of the use for which the metal is desired. It is simply a brief means of setting forth the fact that the metal in question has been made by a fusion process, as distinguished from those used in the manufacture of other metals which have iron ore for their basis.

RAW MATERIAL.

General note.—The raw materials of the steel industry, those of the "iron" group as distinguished from fuels and refractories, are: (1) iron ore in its various and widely differing forms; (2) pig iron as made in the blast furnace; (3) wrought iron as made in the puddling furnace, and (4) blooms as made in a machine puddler from pig iron, or in a bloomary fire from ore. To these may be added the scrap which is made in shearing plates, in cutting rails or bars to net lengths, and the miscellaneous supply of old and worn-out steel material, which is gathered from many sources, and which constitutes quite a perceptible fraction of the whole stock called for by steel melters. The use in the manufacture of steel of these last-named materials should be spoken of rather as the remelting than the making of steel, although this distinction need not be drawn very closely. A table is herewith given of analyses of these materials of the iron group, not as being interdependent or as derived one from another in the least degree, but simply as a means of indicating that they are related to each other, although at the same time they differ very widely in the ratios of the elements of which they are made up.

Typical composition of steel-making materials.

	Metallic iron.	Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Silica.	Alumina.	Lime.	Magnesia.
Iron ore (American):										
High	67.30	......	......	......	.02	.06	2.00	.80	.50	.45
Medium	59.64	......	......	......	......	.02	7.50	2.30	4.10	.62
Low	50.80	......	......	......	.60	.03	9.03	......	......	......
Pig irons:										
English high grade	......	......	3.95	.42	......	.03	......	......	......	......
English low grade	......	......	1.30	.68	.15	1.75	......	......	......	......
Pennsylvania high grade	......	......	2.42	.49	.05	.13	......	......	......	......
Pennsylvania low grade	......	......	.50	1.60	.08	2.90	......	......	......	......
Missouri	......	......	3.02	.27	.00	.08	......	......	......	......
Ohio	......	......	2.55	.23	......	.09	......	......	......	......
Spiegel:										
Twenty per cent	......	5.26	1.08	20.27	.02	.07	......	......	......	......
Eighty per cent	......	4.96	2.29	82.04	.05	.21	......	......	......	......
Wrought iron:										
Champlain bloom	......	.23	.09	.08	.01	.02	......	......	......	......
Good bar	......	.03	.18	.03	.01	.25	......	......	......	......
Steel:										
Hard tool	......	.95	.04	.12	.01	.02	......	......	......	......
Average rail	......	.44	.14	.82	.04	.07	......	......	......	......
Best plate	......	.14	.02	.32	.03	.02	......	......	......	......
Nails	......	.09	.02	.35	.03	.08	......	......	......	......

Very large amounts of these materials are used of the exact analyses given in this table, although it is true that there are some qualities of steel made for which it would be inexpedient to attempt to use any of them, and it is also true that there are many admirable grades or kinds of these materials made in all the divisions of this group of quite different composition from those here shown.

Generally speaking the art of the steel melter lies in the prudent selection he must make daily from the range of crude stock which he is compelled to use, either by reason of the location of his works or the variations in current price in the market from which his supply must be drawn. The prime test of skill in such work is the maintenance, whatever may be the stock used, of the standard of quality specified in any given case or fixed by the general requirements of the time. Instances have been known in which the closest study and the highest qualities of management and contrivance have been called for to prevent loss from the use of low-grade material which had accumulated unawares or by reason of some special exigency of purchase. It should also be observed that experience shows conclusively that the selection and use of the materials for steel making need to be considered from the very first with reference to the desired product and the mode of manufacture, as the quality in all its essential particulars is completely fixed before the final crystallization of the metal in the ingot mold. Hence no subsequent treatment can suffice to save or to improve poor steel, short of an entire remelting and recomposition with fresh and improving materials.

Brief mention will be made farther on in this paper of some of the relations which these materials bear to the processes of steel making in which they are employed. Some note may properly be taken here in a very general way of the influence which is exerted by each of the chief elements entering into the composition of these ores and metals upon the combinations which steel melters seek to make with them. These elements, taken in the order noted in the table, are carbon, silicon, manganese, sulphur, and phosphorus.

Carbon.—This is the chief hardening element in the metal; not alone in the sense of tempering, for a steel which cannot be properly tempered or hardened by any ordinary method may be made to vary to an important degree in this valuable quality by changes in its proportion of carbon. Wrought iron contains either no carbon at all or but slight traces of it, while mild steel, such as the boiler plate noted in the table, may contain a very perceptible quantity. Upon the proportion of carbon which may be present, more than upon any other single element, the tensile strength of the metal appears to depend, although at the same time it is true that the methods of treatment during the manufacture, the melting, and any subsequent treating may be such, either by design or by accident, as to modify to an important extent the strength of the metal which might be expected to correspond to the proportion of

carbon shown by analysis. It is found preferable that the carbon should first be almost wholly eliminated from the metal in steel-making processes and that by recarburizing the needful steely qualities should be given. In this way a far greater uniformity of quality can be obtained than by stopping the process of conversion when the proportion of carbon has been reduced to the limit called for in the finished metal.

Silicon.—This element is present in widely varying proportions in metals as made by different manufacturers for substantially the same purposes. It appears at best to be a source of weakness in the metal, and may perhaps be truthfully said to be tolerated because it cannot be entirely eliminated without leading to the presence of blow holes or other structural imperfection in the ingot. If present in excess it tends to produce brittleness, apparently by separating mechanically the atoms of the metal and thus weakening their molecular attraction for each other.

Manganese.—The proportion of this element which shall be permitted to enter the composition of a steel designed for any given purpose is a somewhat closely disputed point. The chief part which it plays appears to be the prevention of the formation of an oxide of iron in the body of the metal during the process of manufacture, the effect of this oxide when present being to make the metal "red short" or brittle when heated for rolling or hammering. In order to prevent this red shortness it is desirable, and for some purposes absolutely needful, that there should be some manganese continually present in the metal while under treatment in the furnace, so that the oxygen which from any source may tend to attack the metal shall find a closer affinity in the manganese and so pass off into the slag. It is held by many that no more manganese should be tolerated in the finished steel than shall fulfill this single purpose, and that any excess above this limit simply adds needlessly to the burden of impurity, with an important part of which at the best the steel must contend. The manganese is added to the steel in the recarburizing material which is put in at the close of the operation in the Bessemer and open-hearth processes. The preference is growing for the use of the spiegel or ferro-manganese (the recarburizers employed) in the solid state, although it is heated to a full red heat for the purpose of insuring most certainly an immediate and complete melting and assimilation in the decarburized metal. Thus the loss of the manganese, a costly element, due to the earlier method of using it in a melted state, is largely prevented. But for the higher qualities of crucible steel it appears desirable, if not quite essential, that the material used should be made from an ore which contains manganese, so that the structure of the finished metal shall be as absolutely homogeneous as possible in this respect.

Sulphur is tolerated in steel simply because it must be; or, more correctly, because it is found in and cannot be entirely removed from the raw materials which on the whole are available and desirable for use

by any means practicable in the present state of the art. Hence it is kept as low as possible, the extreme limit within which it may be allowed being the appearance of a tendency to red shortness in the rolling or other working of the ingot.

Phosphorus.—This is the most trying element to steel makers, as it is found in nearly all iron ores; it all goes into the iron when reduced to the metallic state in the blast furnace, and up to the present day it has defied all efforts to keep it out of the steel, except in the very latest, the "basic" process of conversion, to which farther reference will be made. The tendency of the phosphorus when present in the steel is to render it brittle, although the degree to which this tendency shall prevail depends to an important extent upon which and how much of each of the other elements are present at the same time.

Careful study of the wear of rails has been made, taken together with extensive analyses of known cases of wear, in the expectation or hope that some direct or useful clew could be found to the best relation which these elements should bear to one another. It does not appear, however, that the facts in the case have yet been so fully developed as to warrant such a summary of the whole relations of these elements as shall command the approval of all who have aided in the gathering and the study of these facts. All indications seem to agree that some of the important physical qualities of steel do not depend solely upon these elements which may be present even in proportions that had seemed fully approved, but rather upon some additional relations, still somewhat obscure, between them, or the relation which these bear to the molecular structure of the metal as a crystalline body.

Rare metals in combination.—These unusual metals, such as chromium and titanium, either very seldom found at all in combination with steel or in extremely minute quantities, have formed the subject of careful study among experimenters, but it does not appear that they possess any importance whatever to the steel manufacturer or consumer in the large majority of cases.

PROCESSES.

Kinds.—The processes of making steel which will be described in this paper are three—the "crucible," the "Bessemer," and the "Siemens" or "open hearth." Others are worthy of mention, but may be passed as of less importance in this connection. In very general terms these processes are: (1) In the "crucible," the addition of carbon to a pure wrought iron, so that the steely qualities shall be thus given to it; (2) in the "Bessemer," the removal of the carbon by burning it out by a blast of air forced through the melted pig iron; and (3) in the "open-hearth" process, the dilution of the carbon in the pig metal by the addition of wrought blooms or steel-scrap stock. In each case the addition or removal of the carbon is continued until the tests, taken either at the moment or for a whole series of operations, show that the limit called for in the metal under treatment has been reached. These processes

can best be described in immediate connection with the particulars to be given of the materials used and the furnaces and other apparatus required.

The crucible process.—In this process the raw material is usually bar iron. In the strict use of the word the steel is "made" in a converting furnace and simply remelted in the crucible, although additions to the converted metal may be made, and often are, in the contents of the crucible for the purpose of changing or grading the metal as needful during the actual melting. The bar iron for the finest grades of crucible steel is usually brought from Sweden, being made there from extremely pure ores, with the use of charcoal as fuel. These bars, about 3 inches wide, five-eighths of an inch thick, and 9 feet long, are piled in a suitable inclosed furnace with alternating layers of charcoal and carefully covered in from the air. They are kept at a high red or yellow heat for several days, or until the carbon of the charcoal has been absorbed to a greater or less degree by the iron. After cooling slowly these bars are withdrawn from the converting furnace, and are found to be brittle and quite transformed in the appearance of the fracture at the end of the bar when broken across. The steely quality appears in this fracture in the change from a fibrous or half-crystalline appearance to a much clearer or brighter crystalline texture, reaching part way inward from the surface or entirely through the bar, according to the length of the exposure in the converting furnace. The bar iron has thus been more or less fully converted into "steel," and for some purposes it is used without any further treatment except that of reheating and hammering or rolling to any required size or form of product.

For most purposes this metal, now known as blister steel, is cut or broken up and put into crucibles, which are heated singly in coke "melting holes" or in a group in a gas furnace. When fully melted the contents of the crucible are poured into an iron ingot mold placed close at hand on the floor, and in this the steel is allowed to cool. After the ingots have cooled the end of each is broken off, so as to expose a clean, fresh fracture, and by the character of this fracture an experienced man assorts the ingots according to the percentage of carbon which each contains. They are next carried forward to a completely finished state by hammering or rolling, with such reheating and annealing in their progress as the character of the metal and the use for which it is intended may indicate or require. The crucibles hold from 50 to 100 pounds of metal each, and are made of clay carefully selected and so worked that a uniformly high quality may be maintained, both in respect to the effect which may be produced by it upon the contents of the crucible and also the endurance it must exhibit at the intense heat to which it is subjected in the furnace. These furnaces for many years were heated only with the finest qualities of coke, and in some works these coke-melting holes are still retained. Each hole is usually large enough to contain two crucibles, and after they have become somewhat heated

in the hole the stock, cut into small pieces, is put in. A lid of clay material is put on the crucible and the hole is filled with coke. The heat is controlled by brick dampers so that after the four or five hours required for the melting have passed, or during that time, the completion of the process of melting or grading may be hastened or retarded, as may be found needful. It will readily be perceived that this intense heat, when hard coke is used, can be continued only at a great expense for fuel. This is a serious hindrance to the use of the fine grades of crucible steel, although some melters believe that only by the use of separate holes thus heated can the needful control of the quality be preserved.

A more recent means of heating these crucibles has been found in Sir William Siemens's "regenerative gas furnace," in which a large number of crucibles may be placed. These are usually set in the furnace in groups of four, and the number of groups placed in one furnace varies from three to fifteen or twenty, according to the need or preference of the builder. The groups are usually quite separated from each other by the brick work of the upper part of the furnace, but the crucibles are equally heated by the gas flame, which is maintained by currents of air and gas entering through ports on one side. This flame passes out of the chamber through similar ports on the other side, and the intense heat of this spent flame is absorbed by masses of firebrick piled loosely in the pair of "regenerators" or heat-storing chambers under this outgoing side of the furnace. A similar pair of regenerators stands beneath the side of the furnace at which, for the moment, the air and gas enter, and by suitable reversing valves the flow of the air and gas and that of the outgoing flame or waste gas are controlled or turned from one side of the furnace to the other. By this means, after the furnace and regenerators have been heated by repeated reversings to their normal working temperature, it becomes possible to maintain at the expense of the heat in the waste gas or flame an even and very high temperature in the currents of gas and air as they enter the furnace. Thus the heat developed by their combustion, in the chambers around the crucibles, is entirely available for heating the crucibles themselves and their contents, and need not be expended in any degree in the heating, to this intense temperature, of any of the incombustible elements which must necessarily be present in the gas and air supplies. In the "gas producer" designed by Sir William Siemens for use in connection with this regenerator, the cheaper grades of "slack" coal or dust can be used. The carbon which these contain may be almost wholly converted in the producer into a combustible gas, which is led away to the furnace through suitable pipes or flues.

The use of this furnace with its important range of control, its intense power, and its adaptability to the cheapest forms of fuel, is by no means universal as yet for crucible-steel melting. In no part of its field of

usefulness, however, has the advantage of its employment been so marked, and the tendency is toward a more extended use each year.

The Bessemer process.—In this the raw materials are pig iron, steel scrap, and spiegel or ferro-manganese, these last two terms being to a certain extent interchangeable. The crude pig iron is run in a melted state into the "converter," an egg-shaped vessel which is hung upon trunnions so that it may be rotated, by suitable fixtures, from a vertical to a horizontal position, in fact usually within the entire limits of an arc of 270 degrees. The iron is run into the vessel through the mouth or nose, an opening at one end, while it lies in a position nearly or quite horizontal. The vessel is lined throughout with refractory material from 8 to 12 inches thick, and in the lining of the bottom of the vessel are imbedded ten or more tuyeres. These are blocks of firebrick material 20 to 24 inches long and 7 inches in diameter, slightly conical in shape and pierced from end to end with holes seven-sixteenths of an inch in diameter. These holes open freely at one end of the tuyere into the converter, and at the other end into the "tuyere box," so that the refractory lining of the bottom of the converter is pierced with a hundred to a hundred and fifty holes through which the air may be blown into the metal contained within it. Into the tuyere box a pipe leads from one of the trunnions, and through this trunnion, from the blowing-engine connection, air is forced at a pressure which varies at different works from 15 to 50 pounds per square inch, according to the power of the engine or the preference of the manager. The air valve is opened before the vessel is turned into the upright position, so that the melted iron is kept out of the tuyere box by the force of the blast; and as soon as the vessel is turned up the molten metal is thrown into violent agitation by the numerous streams of air which enter under high pressure through the small holes in the tuyeres. An oxidizing action at once begins: the silicon in the mass of iron is first attacked, and later the carbon is in like manner removed by combination with the oxygen of the blast, the minute subdivision of the mass of iron by the mechanical effect of the blast serving in an important degree to promote these reactions. During the twelve to twenty minutes required for the blowing of a "heat" the temperature of the metal continually increases, this being indicated in part by the intensity of the flame at the open nose of the vessel. This flame is but trifling at the beginning of the blowing, but it increases until at the close it is very compact, issuing with violence and great brilliancy from the converter. During the blowing of the metal it is sometimes found needful, in order to reduce or to regulate the intense heat which is developed, to put into the converter scrap steel of such kind as may be most available at the moment, generally the crop ends of rails or similar pieces which have been thrown aside during the later operations of manufacture. In this way, or by putting the scrap into the converter before the pig metal is run into it in the first place, any excessive heat of the mass can be reduced or controlled very com-

pletely, the absorption of heat due to the fusion of the scrap metal thus thrown in being usually amply sufficient to secure this control.

In the large majority of cases the termination of the operation, the instant when the carbon has been almost wholly removed by this combustion process, is very clearly indicated by a rather sudden change in the character and color of the flame. It is reduced in volume and becomes paler and nearly or quite transparent, sometimes almost wholly disappearing, and sometimes being accompanied with large volumes of a thick brown smoke, an indication that the iron itself has begun to be oxidized by the blast. The converter is now turned down, the blast is shut off, and a quantity of recarburizing material, spiegel or ferromanganese, is brought up and poured into the converter from a ladle, or it is run in in a solid state through a suitable spout. This usually combines readily with the intensely heated decarburized metal in the converter, a vigorous reaction and boiling being sometimes produced. The metal, having now been recarburized and having received the needful steely quality, is poured out at the nose of the converter into a ladle which rests in a central crane, and from this ladle the metal is cast, through a nozzle in the bottom, into ingot molds of any desired size or form. From these molds the ingots are removed and sent forward for reheating or direct treatment in rolling or hammering as may be required.

The open-hearth process.—The raw materials of this process are iron ore, pig iron, wrought-iron blooms, steel scrap, and recarburizing material of various kinds and grades. The furnace in which the metal is made, or in some cases simply remelted, is the Siemens regenerative gas furnace of precisely the same general type as that already referred to in connection with the crucible process. In this case, however, the metal is melted, or made, in or on the "open hearth" of the furnace, into and over which the intense flame passes. This process is so called, as differing from the crucible process, in that the work in the latter is done in closed pots or crucibles, which are set in groups in the compartments of the furnace, and are bathed upon their outer surfaces only by the currents of flame. The Siemens furnace for the open-hearth process is somewhat more nearly square, the basin or hearth being in some cases 7 by 12 feet in size, or if larger, in about the same proportion. It is inclosed by substantial firebrick walls, with the needful doorways at the sides, and is covered in with a roof, usually so shaped as to direct the flame somewhat downward upon the body of metal lying in the hearth. The flame traverses the furnace from end to end of the melting chamber, changing its direction of motion with each reversing of the furnace. The currents of gas and air for its supply and maintenance enter through ports at the ends of the furnace, which lead from the regenerators below the melting chamber. After the hearth or "bottom" of the furnace has been brought to a full heat, the raw materials are put in through the doorways, almost invariably in the solid state and

usually without any previous treatment or preheating. For many purposes the stock is piled in so as to fill the furnace completely, the last few pieces being shoved in close under the roof and on the top of the loose pile of material beneath. If the bulk of the charge is made up of heavy pieces the whole quantity required for the "heat" is thus put in at once, but if the furnace has been piled full of lighter stock the remainder is thrown in as soon as the bulk has been reduced by the melting and sinking down of the mass.

For some kinds of metal a quantity of pig iron is put into the furnace by itself and then melted and brought up to a very high temperature. Into this intensely heated bath is put at suitable intervals the remainder of the charge, which, in such a case, is likely to consist of wrought-iron blooms, the ends of steel blooms, and pieces of ingots which for any reason may have been interrupted in going through the rolling mill or forge, and which are almost dead or useless material except for consumption in this form of furnace. These heavier pieces are usually preheated, often to a high yellow heat, so that the actual process of melting shall be made as brief as possible, and (what is even more important) so that the intense temperature of the furnace shall be reduced by the least possible amount by the putting in of any comparatively cold material. As soon as the whole charge has been fully melted a series of tests is begun, which, in general, consists of the taking of a sample of the metal with a small ladle and the casting of a small ingot or test piece. This is cooled and broken, and by the changing indication of the fracture, as the process advances in the furnace, an accurate knowledge of the exact condition of the melted mass is obtained.

In general terms, it will be seen, as already noted, that the open-hearth process consists of the decarburization by an actual dilution of the mass, if the original bath has been made up of pig iron. The wrought-iron blooms often contain but traces of carbon, and the steel scrap only small percentages, varying usually from .2 to .5 of 1 per cent. of carbon. In some cases, in order to hasten the decarburization, iron ore of a suitable quality is thrown into the melted metal in the furnace. This acts by a combination of the oxygen which it contains with the carbon which still remains in the metal, thus causing a useful agitation in the bubbling or boiling by the evolution of carbonic oxide beneath the surface of the melted metal. The metallic iron thus reduced from the ore adds to the contents of the furnace, and the silicious and other earthy matter combines with the slag lying on the surface of the metal, which has been derived in large part from the slow wasting of the material of the walls and the bottom of the furnace itself. This reduction of the carbon continues until it stands at about .08 of 1 per cent., or less, in the contents of the furnace. A quantity of spiegel or ferromanganese is then put in, usually preheated; and after stirring the metal, so that it shall be rendered as uniform as possible, the contents

of the furnace are tapped out into a ladle at a breast which had been made up at the lowest point at one side of the sloping bottom of the furnace. In some cases the recarburizing material is thrown red hot into the ladle, either before or during the pouring into it of the metal from the converter or the open-hearth furnace. From this ladle the metal is run into ingot molds by substantially the same means as are employed in the Bessemer process.

FURNACES.

Varieties.—The furnaces which are used more or less directly in the steel manufacture form quite an extended series, and some have undergone very important transformations and improvements upon their earlier forms, as the absolute requirements of the various operations have been developed, either in the current working or at the moment of repair and rebuilding. These furnaces, using the word in a general sense, if arranged approximately in the order in which they may be said to stand in the advancing steps of the manufacture, would appear somewhat thus, beginning in the series at the very first treatment of the ore:

Furnaces used in iron and steel making.

Order.	Furnaces.	Order.	Furnaces.
1	Calcining kiln.	11	Reverberatory furnace for pig metal.
2	Bloomary forge.	12	Cupola furnace.
3	Siemens rotator.	13	Bessemer converter.
4	Blast furnace.	14	Preheating furnace.
5	Pernot dephosphorizing furnace.	15	Siemens open-hearth furnace.
6	Hand-puddling furnace.	16	Soaking pit.
7	Machine puddler.	17	Coal-fired heating furnace.
8	Cementing or converting furnace.	18	Gas-fired heating furnace.
9	Crucible coke melting hole.	19	Annealing furnace.
10	Crucible gas-fired furnace.	20	Closed forge fire.

It should be borne in mind, however, that the operations of steel making do not require the use of all these furnaces as a continuous series. A rearrangement of the numbers, as given in the groups made below, may serve as a more accurate guide to the general places occupied by each furnace in the processes of manufacture, and also the relation which each bears to others in the same group:

I. Preliminary furnaces—Nos. 1, 2, 3, 4, 5, 6, 7.
II. Crucible—Nos. 2, 4, 6, 8, 9, 10.
III. Bessemer—Nos. 4, 11, 12, 13.
IV. Open hearth—Nos. 2, 3, 4, 7, 14, 15.
V. Finishing—Nos. 16, 17, 18, 19, 20.

A brief descriptive note upon each of these furnaces may be usefully given, together with some particulars of the process carried on in each of them.

Calcining kiln.—This furnace (No. 1) finds only a very limited application in any of the works in the United States, but it may be justly placed in this series, for upon its use depends the profitable working of

important ore supplies for steel making as well as for other parts of the general market grades of iron. It is usually circular in general outline, from 10 feet to 16 feet in diameter, and from 16 feet to 60 feet in height. At the bottom a brick cone, with iron facing, is built in the inside of the kiln, of such diameter and height that the ore, in moving slowly downward after the kiln has been completely filled, shall be delivered at points all around the outer circumference for convenience in loading into the cars or wagons by which it is to be taken away. The ore and fuel are put in at the open top and pass down together. A full red heat is developed by the combustion of the fuel, by which the sulphur and carbonic acid are driven off from the ore, these being the elements for the elimination of which the kiln is most frequently employed. For some purposes kilns of other forms are required, in which higher heats are developed, and in some of them gaseous fuel is used.

Bloomary forge.—This furnace or fire (No. 2) is in its general form the earliest known type or kind of furnace for making malleable or wrought iron. It is quite similar to a large forge fire as used in a smith's shop, although the fuel is charcoal and the fire is contained in a rather deep basin. The iron ore is laid in small quantities on the top of the mass of burning fuel, and is gradually deoxidized and transformed into wrought iron, the particles finding their way down through the fuel and gathering in a mass in the bottom of the basin. From time to time during the day these "loops" are taken out and hammered into blooms, which are cut into two or more parts as required. This form of wrought iron is rarely made from any other than the richest and purest ore and only with charcoal as fuel. The process leads to the production of the purest known qualities of iron, such as will bear the high price which must be charged for them. Nothing has yet been proved so good for use in the open-hearth furnace in making the finer grades of boiler-plate steel or in the crucible process for the best qualities which are called for in that division of the steel manufacture.

Siemens rotator.—This furnace (No. 3), designed by the late Sir William Siemens, has been urged as likely to take the place of the bloomary forge in making crude wrought-iron stock for the open-hearth furnace directly from the ore. Under his own careful management a good deal of useful work was done and some promising developments were made of the possibilities of the process. In other hands, however, less success has been achieved, and there are too many reasons for believing that since the greatly lamented death of the inventor this whole method of direct working has been suffered to fall hopelessly into disuse. This process was in general the same as that of the bloomary forge, except that the use of mineral coal in small quantity was made practicable as an aid in the reduction of the ore to the metallic state. The operation was carried on in a cylindrical furnace about 8 feet diameter by 9 feet long, revolving about a horizontal axis and usu-

ally at very slow speed. To this an admirable adaptation of the Siemens type of regenerator was made, so that gaseous fuel could be employed, with the well-known advantages of a pure flame of any required quality and intensity. It was found however, on the whole, that the uncertainty of the quality of the product, and the high cost, due largely to the waste or loss of material in the process, taken together, were such as to prevent any important use of the furnaces which were built and of their product.

Blast furnace.—This furnace (No. 4) is thus far the best known and most highly perfected form of apparatus for the reduction of iron ore to the metallic state. Indeed, it is impossible to see, in the present state of the art, wherein, in type or kind of apparatus, any farther advance can be made. Improvements in the management and the economical working of these furnaces are recorded almost daily; but some entirely new departure appears to be required before the blast furnace of the present modern form can be spared from the list of iron-producing apparatus. In general outline the furnace is circular, 16 to 20 feet clear diameter, and 60 to 80 feet whole height. This largest diameter is considerably reduced at both the bottom and the top, and the furnace is completely filled with the mixture, made up in correct proportions, of iron ore, coke or coal, and limestone. The furnace is blown by one or more engines of substantial dimensions through tuyeres set in the side walls of the hearth quite near the bottom. The use of the waste gases from the top of the furnace was made practicable many years ago for heating the blast, and for making steam for driving the blowing engine. The adaptation of firebrick stoves for the blast and of carefully designed boilers and other steam machinery appears to leave little room for further important advances in these parts of the apparatus.

At the very high temperature which is developed in the interior of the furnace a series of chemical reactions takes place. The iron in the ore is reduced to the metallic state through the agency of the carbon of the fuel and it is gathered in the hearth or crucible at the bottom of the furnace. The silicious and other earthy elements of the iron ore and the ash from the fuel combine with the lime of the limestone and form a fusible slag, which floats upon the melted iron in the interior of the furnace. At suitable intervals the iron is tapped out from the furnace into molds of the well-known pig-iron form, and at corresponding intervals the slag is run out into cars in which it is carried away.

Pernot dephosphorizing furnace.—This furnace (No. 5) is an adaptation of the general form of the Siemens regenerator furnace to a Pernot hearth or pan, which revolves about an axis slightly inclined from the vertical. The process is substantially the same, so far as it goes, as that long carried on in the older hand-puddling furnace, and it will be more fully described further on.

Hand-puddling furnace.—This furnace (No. 6) has been used from a very early day in the iron manufacture, and though long threatened with extinction, it has survived the advance in every direction around it of greatly improved methods of doing some parts of its work. The field in which it is found essential to success is unquestionably narrowing year by year, and the cost of doing the work of this furnace seems hardly likely to be much reduced. The process of puddling, so far as the manufacture of steel-making stock is concerned, consists in the stirring of the melted pig metal in the basin of the furnace with a hand tool or "rabble" until it assumes a pasty consistency; it is then worked up into a spongy ball and taken out, squeezed into a compact mass or bloom in a "squeezer," and rolled out into a flat strip known as "muck bar." The elimination of the carbon, phosphorus, and silicon from the pig metal, by the intimate contact in the furnace with the iron-ore fettling or lining and the silicious slag which is mixed with the melted iron, is very complete. The metal produced under favorable circumstances is so admirable a material for many purposes that it is certainly somewhat to be regretted that any causes should have led to a decline of this branch of the general iron manufacture. At the same time it appears to be undeniably true that an important part of these causes has been the imperfect agreement between those concerned as to the value of the work done as compared with the cost of doing equally good work by other means or in the use of other forms of apparatus.

Machine puddler.—This furnace (No. 7) appears likely to take in part the place occupied for so many years by the bloomary forge and the hand-puddling furnace. The process is nearly or quite identical with that carried on in the hand-puddling furnace, except that the masses of metal dealt with at a single heat are far larger and the costly labor peculiar to the hand furnace is wholly saved. Other labor is required, however, but at very much less cost in proportion to the product of the furnace. The metal may be melted in the puddler itself, a cylinder 8 feet in diameter by 9 feet long, revolving about a horizontal axis, or it may be held after melting and partially desiliconized in a gas-heated reverberatory furnace. By the rotation of the puddling furnace the metal is rapidly "brought to nature" or into the pasty state. The balls are taken out and hammered into very solid, compact blooms, under a heavy hammer which expels completely the traces of the slag in which the particles of metal were enveloped in the furnace. At the comparatively low heat at which this process is carried on it is practicable to hold the phosphorus which may have been originally contained in the iron in the slag, although this cannot be done at the high heat of a steel-melting furnace. Hence, by the use of a heavy hammer at this stage of the manufacture, an important result is obtained in the elimination of this hurtful element, and the use is thus rendered possible of important quantities of pig metal which would be otherwise quite unavailable. It should be farther noted in this connection that these blooms may be taken from

the puddler, if designed for the open-hearth furnace, before they have become entirely decarburized or reduced to the true wrought-iron state. In this way the product of the puddler is increased for a given time, the waste of the metal in it is somewhat reduced, and the proportion of carbon remaining is entirely manageable in the steel furnace. An important feature of the use of this furnace is the possibility of the rapid transfer of the hammered blooms, if so desired, to the open-hearth furnace before they have become cooled much below a full red heat Thus a clear saving may often be made of the time and fuel otherwise required for the heating of the blooms from the cold state. Extended practice with a furnace of this type has shown that the phosphorus can be reduced to one-tenth of that originally contained in the iron, even though this may have been only .04 of 1 per cent.; and that the work can be done with a consumption of fuel not exceeding 1,200 pounds of coal per ton of blooms in a non-regenerative furnace. Americans have taken a most honorable part in the development of this branch of manufacture.

Cementing furnace.—This furnace (No. 8) has been referred to in another connection, and it may suffice to say here that considerable numbers of them have long been in use and that they bid fair to continue indefinitely as an essential part of the apparatus required in the production of the high qualities of harder grades of steel.

Crucible melting hole (coke).—This furnace (No. 9) has been already. briefly described. The holes are usually built in a row, each one having its own separate flue. This to a certain extent renders it possible to repair or to use separately any one of the holes with little interruption to the working of those next to it.

Crucible furnace (gas-fired).—This furnace (No. 10) is worthy of more extended mention, as it has been proved to be a means of greatly reducing the cost of fuel consumed in the crucible process and of repairs upon the furnace parts. The essential features of this furnace, common to all which use the Siemens or "reversing" type of regenerator, are the heating or melting chamber of the furnace in which the work is done, the ports leading from this (the upper) part of the furnace usually directly downward into the regenerators, the brick filling of these heat-storing chambers, the flues and valves through and by means of which the flow of gas, air, and waste gas is controlled and directed in the working of the furnace. The regenerator filling is made up of hard firebrick, usually 2¾ by 2¾ by 9 inches, laid dry and spaced about 1 inch or more apart. The bricks in each course are laid across those in the course beneath, and thus a mass of brickwork is obtained pierced in every part with small passages or flues, which by their large combined area give an ample freedom to the movement through them of the gaseous currents. The waste gas from the furnace, when in a normal condition of working, heats the upper fraction of this body of brickwork to a temperature corresponding to its own intensity and to a consider-

able depth below the extreme upper courses, and it finally escapes from the regenerator, often at a temperature only a little above that of boiling water, into the chimney flue through passages which lead out from beneath the brickwork filling and through the reversing valves. The gas producer is elsewhere described. The gas and air enter the furnace through the reversing valves and pass upward through the spaces in these masses of intensely heated bricks. They are thus heated at no expense of fuel to nearly or quite the very high temperature of the interior of the furnace itself before entering it. The admission of the gas and air is very conveniently controlled by separate stop valves, so that by maintaining a proper excess of gas in the furnace flame all cutting or oxidizing and wasting of the metallic contents of the furnace are prevented. If, on the other hand, an oxidizing flame is required for the special work in hand in the furnace at any moment it may be obtained by a turn or two of the valve wheels which control the supply. This type of furnace stands in all its essential details where it was placed by Sir William Siemens and his immediate associates fifteen or twenty years ago. Few radical improvements, if any, have been made, although changes almost innumerable in detail have been attempted. Next to the Bessemer converter this furnace has been the chief means of advancing the manufacture of steel, and of iron as well. The economy of fuel, the completeness of control at all temperatures, the efficiency of operation, especially at the highest heats, and the possibility of securing an extreme advantage in economy of labor—these considerations all join to render the use of this type of furnace not only important but essential to the successful continuance of the whole steel industry of the world. American builders have had an honorable part in the study of the adaptation of local materials to the work to be done in these furnaces and in the contrivance of special details or proportions of parts.

Reverberatory furnace for pig metal.—This furnace (No. 11) as placed here in this current series is simply referred to as employed at an early day for melting the pig metal for use in the Bessemer converter, but in this country it was long ago abandoned for such work. This type of furnace when thus used was hopelessly slow in melting and very wasteful in fuel. As rearranged for gas firing with regenerators, and for use in premelting for a machine puddler, it leaves little to be desired in respect to economy and convenience.

Cupola.—The use of this furnace (No. 12) was a very important step in advance in the adaptation to American needs of the general plant for making steel which was so highly perfected by Sir Henry Bessemer. Speed of melting the iron for conversion was quickly found to be absolutely essential to progress, and the so-called "cupola," long known in iron foundries, was brought into use. This is a cylindrical furnace about 8 feet in diameter and 40 to 50 feet high. About 20 feet from the bottom is set the charging door at which the materials are put in, pig

iron, sometimes steel scrap, coal or coke, and limestone. About 3 or 4 feet from the bottom the tuyeres are set in the wall, from six to twenty or more in number, and they are supplied with blast from a suitable blower, each tuyere having in nearly all cases its own external connection to the blast main. If a large number of small tuyeres are used they are generally fed from a belt or chest set against the shell of the furnace and extending entirely around it. The melted metal is gathered in the lower part of the furnace and is tapped out into a ladle at convenient intervals. The slag which is formed by the combination of the limestone with the ash of the fuel is run out through a tapping hole usually set in the back of the furnace. Changes have been proposed from time to time in the outlines of these cupola furnaces as adapted to the rapid melting in continuous operation of large quantities of iron, and some of these modifications have been put into use. It is by no means certain, however, that any better results have been obtained than have followed the adherence to the earlier straight outlines, which are much more readily kept in good working order. Careful attention to details of mixture of fuel and of charging the furnace are found to have an important bearing on the efficiency of the whole. The length of time during which one of these larger sized cupolas can be kept in free working order varies from two to four days, and during that time it can be made to melt freely from 8 to 10 tons of iron per hour.

With the growing attention which is given, and must be, to the use of "direct metal" from the blast furnace in the converter, the cupola as a melting furnace becomes less important. Some works still use it in melting all the iron supplied to the converter and some for the "Sunday" iron only. There is still need that care should be taken that the work it does shall be well done, and hence almost constant study has been given to it to promote its efficiency and economy. The only duty required of this furnace is to melt quickly and cheaply, and the limit of the most efficient working, in cost in fuel, is about 12 pounds of iron to 1 pound of a mixed fuel, one-third coke and two-thirds anthracite coal. Two changes of some importance have been made during the last few years in construction and arrangement. One is the increase in the height of the cupola from the base to the charging door, so that more material is in the furnace at any given moment, and hence there is a larger useful absorption by it of the heat proceeding upward from the intense combustion in the lower part of the furnace, which otherwise would pass away into the open air and be wasted. Another improvement which has led to an important saving of labor is the dropping of the sill of the charging door close down upon the floor of the gallery on which the materials are brought to the furnace. Thus it becomes possible to run all these materials directly into the furnace without any hand work or with the least possible. In some of the large cupolas two or more charging doors are cut in the shell, and through them the stock can be more uniformly spread than through the single door formerly used.

The *Bessemer converter* (No. 13) is not a furnace in the sense in which other kinds of furnace apparatus are spoken of, in which an application of heat from some external source is made, more or less directly, to the metal under treatment. The metal takes with it into the converter within its own substance the fuel, carbon and silicon, needed not only to keep it from being chilled by the blast of air admitted through the tuyeres, but also to maintain the whole mass in a melted condition, even after these elements have been nearly or quite burned away. In other words, by the oxidation of these elements the heat of the converter and its contents is gradually raised from about the temperature of the melted pig metal to that of melted steel, from a high red heat to a brilliant yellow or a dull white. The heat thus developed is sufficient not only to raise the temperature of the metal itself, but also that of the great volume of air passed through it from the blowing engine, and also to heat to the full limit the inner surface of the refractory lining. In case the metal is more than usually high in silicon there is a reserve of heat still available for melting the steel scrap, which is then put in to control the extreme temperature thus developed. The converter in all its essential points is the conception of Sir Henry Bessemer, who at the first advanced the whole in all its marked features to the complete state in which it is now found. American engineers have added from time to time useful details of construction, which have been proved to be indispensable since the pressure has become so extreme for rapid and economical working. Several sizes of these converters have been built and are now running, but the preference is very marked in the later works for those of moderate capacity. Some unexpected results have been obtained in the operation of the smaller converters, some of these of a nominal capacity of 4 tons for each heat having been so stimulated as to press very closely upon the record of production of those of twice the size.

The *preheating furnace* (No. 14) is an aid in the open-hearth process and in the production of some grades of steel in which the heat of the melting furnace must be kept at an extremely high point it is essential to the obtaining of the best results. Generally speaking, it is found preferable that the melting furnace should be kept for use strictly as a melting furnace, and hence that the stock, especially the heavier pieces, should be brought to as full a heat as possible before being put into the melting chamber. This method of working preserves the more friable refractory material in the roof and walls of the melting furnace from the liability to injury by the cooling due to putting in cold stock. It also preserves and holds more effectively for immediate use the reserve of heat in the regenerators, as contrasted with the loss of heat due to the absorption by the cold material. The most important use of these preheating furnaces has no doubt been made in the works abroad, in which very large masses are melted and held for treatment and for subsequent additions of material, and in which the added cost of labor due to this

second handling after preheating does not form so impertant an item as here. The furnace may be either gas-fired or worked direct with coal. The heat at which it is run is not so high as to lead to any important loss by oxidation if the coal flame plays on the metal. When the furnace is so placed that the stock can be run by an inclined spout directly into the door of the melting furnace the convenience and economy of working it are very marked.

The *Siemens open-hearth furnace* (No. 15) has already been commented upon in respect to some of its important features in connection with their use in the crucible furnace. The advantage attending the use of the furnace as a whole is even more noteworthy as a means for melting on the open hearth, for thus it has been made practicable not only to melt any material whatever (as regards size of piece, kind, or quality) likely ever to be used as a raw material for steel, but also (what is more important) to hold it for any probable time whatever at its full fusing temperature, for the purpose of testing its quality and applying such additional or modifying materials as these tests or the working of the furnace may indicate. These furnaces have been built in all sizes, from those which hold only 3 tons of metal in the shallow basin-shaped hearth up to those which can take in 20 to 36 tons at a single melting. Most of them hold from 10 to 15 tons under ordinary conditions of working. The range of qualities which may be produced through the agency of this furnace and held under accurate control is wide; so wide and so clearly marked in fact that there appears to be little room for any important advancement in the possibilities of this branch of the manufacture except by some wholly new and radical transformation of which the present state of the art gives no sign or promise. The important advances made in the construction of these furnaces during the few years just passed have related almost solely to the details which have to do with reduction of first cost and of repairs. The endurance exhibited by one of these furnaces as now run by a prudent melter is very marked as compared with that which was found common at an earlier day. This is due to an improvement in the actual handling of the furnace itself, and even more to the advance made in the character of the firebrick and other refractory materials employed. In some cases important attempts have been made to modify the arrangement of flues and regenerators with reference to their connection with the melting chamber. There may fairly be supposed to be still room for saving in cost of repairs in these particulars, but the general principle holds good in these lines or forms of construction that the cost of experimenting in new directions is so heavy and the delay due to failures so serious that few consider themselves warranted in taking such risks except in what may be called very small fractions of construction, from which a change back to the original approved outline may be quickly and cheaply made if need shall compel it.

The *soaking pit* (No. 16), or equalizing cell, as it might be more accu-

rately named, is a device long since thought of, but it has been brought into actual current use only within a very short time. In a few words, it is simply a cell or pit, in a heavy mass of firebrick work large enough to take in a single ingot. Several of these are built in a compact group, sometimes with an iron lining in each, sunk below the floor or so that the mouth of the pit shall be at the floor level, and into them the hot ingots are put as soon as they are lifted from the casting pit. Under all ordinary conditions of working the ingot molds are stripped off from the ingots as soon as their outer surfaces have been cooled, by standing, to a high red heat or a low yellow. The ingots at this point are still in a liquid state in their interior, or at least in a pasty condition, so that if the attempt were made to roll or to hammer the metal without any reheating of the outer crust, or a proper cooling of the inner part, it would be wholly destroyed by the cracking and breaking up of the outer shell and the scattering of the softer interior. It was, therefore, found necessary from the first to reheat the ingots, even if they were not allowed to cool entirely before they could be rolled or hammered. As some of them were unavoidably cooled by the chances of irregular working, ample furnace capacity had to be provided for reheating these from the cold state. The hot ingots have heretofore been put into these furnaces for the "equalizing" required, or until the shell of the ingot had been heated again to the proper temperature for rolling, in part by the absorption of the heat radiated from the liquid or pasty interior and in part by the external action of the heated atmosphere of the furnace. In some cases it has been found that even in quite skillful hands the chances of wasting or oxidation in this reheating furnace have been important and such as should be avoided if possible. This as a chief reason led to the development of the soaking pit, which, in the theory of its action, is perfect within the obvious physical limits which exist. If the mold can be invariably stripped off at or above a certain temperature, there must unquestionably be heat enough remaining in the interior of the ingot to reheat the outer crust to the needful temperature and to allow for the loss due to exposure while being placed in the pit, and also to supply the fraction of heat lost by the radiation into the surrounding earth, that is, to keep the pit itself fully heated to the required point. In theory also it is perfectly practicable to maintain a non-oxidizing atmosphere in the soaking pit, while the ingot remains in it from twenty to thirty minutes, so that the waste due to this process of self-reheating shall be the least possible. This is rendered certain by the close covering up and sealing of the pit after the ingot has been put in. A speedy combustion of the oxygen in the air remaining in the pit takes place, or its expulsion is assured by the gas which is usually evolved from the hot ingot.

Some of the difficulties which have attended the use of the soaking pit are worthy of mention and brief consideration. It is obvious that if the ingot or any part of it, as the smaller end of a large one, gets

too cold before it is put into the pit, it cannot thus be equalized. It is also clear that if in any way the pit itself becomes too much cooled, there must be an interruption until by the passing through it of several hot ingots or by some added fire heat it has been brought up again. Nor is it by any means impossible that by a delay in the rolling a part of the ingots, or all of them, which are actually in the pits may become too much cooled. In other words, the absolute control of the process, upon which all such operations must depend for their success, is far from being complete. The cost of labor in the handling of the ingots cannot be materially less than that called for in the ordinary furnace work which is more common, and the ability to regulate and hasten or retard the heating or equalizing in these furnaces, as indicated by delay at the casting pit or the rolling mill, is ample. This leaves the question of oxidation or wasting still open, and however true it may be that a loss of this character is that of a metal of comparatively high value, the test of extended experience alone can show how valuable, on the whole, this method of treatment in the soaking pit really is to the steel manufacture.

In some of the oldest steel works the impossibility of so placing the soaking pits that they should be conveniently supplied from the casting pit has been clearly shown. This has led to the contrivance of a group of the pits so joined and mounted on a truck as to be portable, the truck being designed to serve as a transfer car to the rolling mill, and thus to accomplish a double purpose.

The occasional imperfect working of the earlier soaking pits suggested the design of a gas-heated furnace, with cells so arranged as to receive four ingots of ordinary size in substantially the same way as they had been placed in the soaking pit. This plan had the obvious advantage of assuring the perfect control of the heating, so that little or much fuel could be used as required, and in new works it furnished also probably the best means of taking care of all the ingots made, whether cold or hot; that is, a means of soaking or equalizing all the ingots brought forward in a direct way from the casting pit, and also of reheating from the cold state all that had been delayed.

Heating furnace, coal-fired.—This furnace (No. 17) is in general type or kind the one universally employed for many years, in both the iron and the steel manufacture, in the reheating of the metal for the later operations of hammering and rolling. In general outline the furnace is rectangular, 4 feet wide by 12 feet long being a common size of the sand bed on which the iron "piles" or the steel ingots or blooms are placed for heating. At one end is the fire box, separated from the heating chamber by a bridge wall over which the flame passes. The coal lies on a grate with the ashpit beneath, and the fire is in some cases forced by an artificial blast. At the farther end of the heating chamber the outline is narrowed down to the size of the stack, or uptake flue, which is built over this neck or reduced part of the furnace.

The whole is inclosed with substantial walls and roof. Doorways are put in for convenient access to the interior of the furnace, and the whole is bound in all directions with iron plates and rods, not only to sustain the thrust of the arched roof but also so as to support the side walls, which, with the wide changing of temperature of the furnace, soon become cracked and lose somewhat the strength which as simple brickwork they may have had in the first place.

This coal-fired furnace has been built in a few instances of late years in a "slope" form, or with the end of the bed nearest the neck of the furnace considerably higher than the other end. In this furnace the ingots or blooms are put in at the upper end one after another, and as they become gradually heated they are rolled over down the slope toward the hot end of the furnace. The ingot or bloom nearest the bridge wall or fire box is drawn first, and the next one is rolled into its place for the last fraction of the heating required. The advantage sought in the use of this furnace is the more complete absorption, by the colder ingots at the upper end, of the heat which is developed in the fire box after it has spent itself as fully as may be needful in heating the hotter ingots at the lower end. It is therefore in a certain sense a regenerative, or more correctly a continuous furnace, at one point in the course of which the cold material may be put in, while at another point the heated pieces may be taken out in a continuous succession. The very obvious disadvantage of such a method of working lies in the cost of labor required for the turning of the pieces in their course through the furnace.

This kind of direct heating usually requires the best coal to be used in the furnace or a grade decidedly more costly than need be used in gas producers if the latter are skillfully run. To this need of a higher grade of coal must be added as an objection to the use of the coal-fired furnace the chance of the blowing over of the coal or the particles of ash on to the pieces which are heating, and the injury by the sulphur or other impurity thus lodged. There is also a serious chance of the fire "working hollow," or into a crust with holes through it, so that currents of free oxygen come over the bridge into the heating chamber with wasting effect at the higher temperatures maintained in the furnace.

From the neck and uptake of a coal-fired furnace the hot waste gas is sometimes led under a steam boiler, care being usually taken that the column of flame liable to be sent out from the furnace shall strike only on a brick arch or shell set in to protect the boiler plates at this point.

Heating furnace, gas-fired.—This furnace (No. 18) is the exact counterpart of No. 17 in the work to which it is applied. It is built in the same general dimensions, but the fire box at one end and the neck at the other end are replaced by a series of ports or passages in the end walls, through which the gas and air currents enter the furnace and

the waste gas passes out. The regenerators are almost invariably placed under the furnace, and the reversing valves at one side or end, usually beneath the floor level. These regenerators, or heat-storing chambers, are almost invariably adopted when Siemens gas is employed, and must be used without exception when high temperatures are called for. A moderate red heat can be obtained with this Siemens gas in a furnace fired with it direct, and it has been somewhat used in this way. In furnaces with regenerators in which natural gas has been used the air alone has usually been preheated. Both of the regenerators at each end of the furnace are devoted to the air supply, and the gas is turned directly into the furnace ports at the extreme ends of the heating chamber.

Some important secondary fixtures and tools are used at these heating furnaces for handling either the massive ingots or the lighter and more numerous blooms. These are of various sorts, according to the preference of the manager of the works, and consist of substantial buggies and cars on which the pieces are brought to the furnace door by hand power or by a locomotive or wire rope connection. A shaft with a chain drum is sometimes used to drag the piece into and out of the furnace. Some use a hydraulic cylinder for obtaining this motion, the object aimed at being the same in each case, the certainty of prompt operation and the greatest economy of hand labor in the moving of the heavy pieces. For the lighter blooms a "peel" (a narrow-bladed long-handled shovel), hung by a gooseneck to a light crane, is generally used. This crane is so placed near the furnace that the bloom can be picked up from a buggy near by and swung around and pushed clear in at the furnace door to the exact spot in which it must lie while heating.

Annealing furnace.—This furnace (No. 19) takes on various forms and sizes according to the uses for which it may be required or the shape and weight of the pieces for which it must be specially adapted. Generally speaking the object of the annealing process in steel working is to relax the condition into which the particles may have been brought by some unequal cooling or working, in order that the molecular attraction of these particles may be permitted to act normally, bringing the whole texture of the metal into a state of uniformity in this respect. The advantage of annealing steel castings and some other pieces is disputed by many, the objection being apparently as much to the method of doing the work as against the principle underlying it. Almost any form of heating furnace can be adapted to this work of annealing, although the rate of heating and cooling, an important point sometimes, generally needs to be more carefully controlled and to be slower than is common in the usual working of any ordinary heating furnace. For this reason such furnaces are almost invariably gas-fired, and have special fixtures or arrangements in their original design for closing them up perfectly airtight. Thus the heating can be carried on at the slowest rate desired and with a non-wast-

ing gas flame, and the process of cooling can also be continued or delayed as long as may be needful.

Closed forge fire.—This furnace (No. 20) is simply one of the lesser conveniences of the blacksmith shop where tools are to be made for use in other parts of a works, or where the work carried on is the forging or the manufacture in a commercial way of all sorts of steel goods. It is of the highest importance that all the heating thus called for, whether for bending or hammering or tempering, should be quickly, uniformly, and, in a word, properly done, in order that the quality of the metal may remain unimpaired and the whole work be done at a profit. This need has led to the contrivance, largely on the part of steel manufacturers themselves, of closed forges, in which, on a suitable grate, a solid fire of hard coal or coke is built and urged as needful with a blast. On the surface of this burning mass of clean fuel the bars which are to be heated are placed, and over the whole is fixed, as a permanent element of the construction and quite close down, a firebrick roof or cover. Thus the metal is bathed in a heated atmosphere as the pieces are turned over during the heating, and the effect obtained is the most gentle and uniform possible. This method of working steel in carefully designed fires, even for such apparently trifling needs, may seem too obvious to require the briefest mention, but the records of the advance of the manufacture as a whole are too full of disappointments and losses dependent upon precisely such things as this to warrant the notion that any detail is unworthy of notice by means of which more exact and correct methods may be secured.

In the furnace department, as devoted to reheating, there must always be room for the less efficient methods to be improved up to the standard or limit of the best. In some cases the actual facts of construction, or the possibilities of fitting new work to old to any advantage, must limit the use of improved fixtures, however desirable they may be. Sometimes, too, the conservatism of managers stands immovably in the path of advancement, even in details concerning which their own judgment has been convinced. The tendency is toward more substantial details of masonry and iron work, to the use of wrought-iron plates and binding fixtures in general, and to the adoption of all such heavier weights and proportions of parts as shall insure the highest durability even at the comparatively low heat at which all this work of reheating steel is done. Even if the soaking pit comes largely into use there must still remain enough reheating to be done from the cold state of the ingot to warrant the use of the best apparatus for the purpose.

In the cost for labor of handling at furnaces much has already been saved by the adoption of the method of direct rolling to the finished rail from the ingot, but something remains for study in some of the works in this respect. The later methods of assigning one crew of men

to the work of several furnaces has proved an important advance over the former practice of giving a furnace to each two men, without reference to the amount or character of the heating done by it. The simplest methods of handling the material, whether by hand or by steam or hydraulic power, are not yet fully recognized as useful, if this recognition is to be measured by their actual adoption and use.

Some important savings in fuel have been effected by sending the blooms direct from the blooming mill to the rail mill without any reheating, or with but a partial reheating as compared with the early practice of allowing them to become wholly or partially cooled. These savings may be readily calculated for any given case or ratio as compared with previous practice by means of some such method of stating the cost as that given on another page of this paper.

FUELS.

Kinds.—The fuels which have been used in the manufacture of steel have ranged from the hardest and purest coke down to the most completely water-soaked dust and other saw-mill refuse which can be made to burn in a "gas producer." Out of this series the items which are used from choice are obviously few in number, and to a certain and important extent they have been used interchangeably. In some localities the question of price determines this choice, as it varies from time to time; and in others the preferences of managers or men rule almost irrespective of price. The chief items in this somewhat extended list of available fuels are given in the table, with analyses. These analyses may be taken as characteristic or approximate, although others can be drawn from equally trustworthy sources which would be found to differ somewhat from these.

Typical analyses of fuels.

	Wood.	Charcoal.	Coal.			Coke (Pennsylvania).	Gas.			
			Anthracite (Mammoth bed).	Bituminous (Pittsburgh).	Bituminous (Illinois).		Blast furnace.	Siemens.	Natural (No. 1).	Natural (No. 2).
Carbon	49.7	88.0	86.8	59.6	70.4	89.3				
Ash	1.9	1.2	5.5	8.2	7.9	10.0				
Oxygen	41.2								.8	.8
Hydrogen	5.9	1.4			4.9		1.0	12.0	22.5	22.0
Nitrogen	1.3						62.0	64.0	7.3	3.0
Carbonic oxide							30.0	18.0	Trace	.6
Carbonic acid							7.0	6.0	2.3	.6
Oxygen and loss		9.4			14.5					
Volatile matter			3.	30.1						
Water			4.3	1.3						
Sulphur			.4	.8	2.3	.7				
Marsh gas									60.3	67.0
Ethane									6.8	6.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Brief mention may be permitted of the uses which are made of these fuels in the ordinary processes of manufacture.

Wood.—This is used more sparingly each year, and almost wholly as a kindling material for the more enduring fuels. Where other kinds of fuel are scarce, and hence costly, it is used somewhat as a supply for gas producers, either in the form of sawdust or of other mill refuse, long and short. When thus used great care is taken to condense out of the gas which is obtained the large volume of watery vapor which is driven off in the producer before the gas is made at all from it. If this were not done the heat would be wholly insufficient in the furnace for many purposes, or if the needful temperature had been once obtained it would be liable to chilling by the influx from the producer of a flood of moisture due to a fresh firing of damp materials. To this chance of trouble from watery vapor must be added the danger of additional and serious oxidation or wasting of the contents of the furnace. Nearly the only important use made of wood in a Bessemer works is the drying and slight heating of the ladles into which the steel is poured from the converter, and even this use is limited to a few works only. In some countries wood has been employed in reverberatory furnaces for puddling iron and in converting furnaces for crucible-steel stock, but to a very limited extent as measured by its proportion of the whole production of these metals.

Charcoal.—This is the fuel of the bloomary forge and of the smaller class of blast furnaces which make so large a part of the higher grades of pig iron. It is also used to some small extent for heating ladles in steel works.

Anthracite coal.—This is used in the production of nearly 40 per cent. of the pig iron made in the United States. In the steel works proper it is used in melting in the cupola furnace for the supply of the Bessemer converting process and to some extent in heating ovens for the drying of spare bottoms for the converters. It also finds an important use under boilers for making steam. The value of anthracite refuse or culm and dust is attracting more attention, especially for steam purposes. Some small amounts are used in gas producers for the supply of heating furnaces, but this use hardly appears to be extending.

Bituminous coal.—This is by far the most important fuel in the whole series to the steel manufacturer. It is very largely used for making steam; in reverberatory furnaces, in which the material is heated by the direct flame from the coal; and in gas producers for the supply of gas to the very important and extended series of regenerative furnaces to which reference has already been made.

Coke.—In steel works coke is used chiefly in the crucible steel-melting holes and in the cupola furnaces in melting for the Bessemer process. Some small quantities are used in the furnace fixtures which are needed for heating recarburizing materials and for drying bottoms used in converter repairs. It is also used for drying and heating the convert

ers themselves after linings have been renewed or repaired. A trifling amount is used in the closed forge fires which are employed in the heating of steel in the later operations of making miscellaneous steel forgings and shapes of all kinds. It is of the highest importance that coke for all these uses should be of the hardest and purest quality. It is used either for producing the highest heats if employed in place of gas for crucible melting holes or in furnaces in which it is brought into direct contact with the iron or steel at high temperature. The impurity most likely to cause injury to the metal is the sulphur which is sometimes found even in the better grades of coke and against which the most careful watch is maintained.

Blast-furnace gas.—This fuel is very largely used in the pig iron manufacture at the blast furnace in heating the hot-blast stoves and the boilers for the supply of the steam machinery. It is a waste product of the operation so far as the furnace itself is concerned, but is of the highest economic importance for these other parts of the apparatus. Its heating power is low, but by the use of an ample area of heating surface in the stoves and boilers the best effects are produced. This gas is sometimes used in the calcining kiln referred to in the list of furnaces. Nearly the only direct use made of it in the steel process itself is that sometimes called for in drying and heating the railroad ladles in which pig iron is transferred in the melted state directly from the blast furnace to the converter.

Siemens gas.—This is so called as a convenient means of noting the difference between it and the "natural gas" of the western Pennsylvania district, and also the so-called "water gas" which from time to time has been brought to notice as of importance to the iron and steel manufacture. Brief mention of the general features of the gas producer should be made here, as being an agent in the preparation of this fuel for distribution and use. In its most common form, a closed furnace or oven about 7 feet by 7 feet by 8 feet high, it was developed many years ago by Sir William Siemens and his associates, and it has undergone only comparatively slight modifications down to the present day. Those changes which have been made have been designed almost solely to lessen the cost of labor in attending the producer, and there appears to be even yet room for some improvement in this direction. The work done by the producer is the transformation, by slow and incomplete combustion, of the bituminous coal into a combustible gas which can be sent through flues and suitable valves into the furnaces in a continuous flow. The ash from the fuel remains in the producer, being formed usually at low temperature and hence without any troublesome clinging to the walls and grates. Thus the supply of fuel to the furnace can be maintained indefinitely, without the slightest hindrance or loss due to the throwing in of fresh fuel into the fire box, as in the more common and older type of furnace which is fired direct, a hindrance which is absolutely fatal to the success of any process

calling for the high and long continued heats of steel making. The producers are usually set in blocks of four, each having a separate connection to a general gas flue, and several of these blocks are connected together, so that the same general coal supply may suffice for all. In a few cases a single producer is made to serve for the supply of a single furnace, but for the sake of greater regularity in the working of the furnace it is more common to use two producers. Thus the chance of the slight diminution of the gas supply, due perhaps to an occasional use of wet coal in one producer or to a slackness in working in the other, in the cleaning of the fire grate, is rendered the least possible; and when a series of twenty or more producers is used working into one common flue these sources of the inequality of the gas supply wholly disappear. Thus the important requirement is fully provided for not only that the steel melting furnace shall run uniformly during the six or ten hours of a single heat, but also that it shall be kept at full temperature for days, as is often needful, and for weeks if required. The fuel in the producer rests in a compact mass on the grate, some 4 to 6 feet deep, and burns with considerable intensity close down to the grate. The carbonic acid thus formed in passing upward through the heated mass of fuel in the producer is transformed into carbonic oxide, a combustible gas which goes out into the gas flue. The hydrogen of the coal is set free at the lower temperature of the upper part of the fuel bed and passes out also. The hydrocarbon elements are also sent over and are usually condensed in the more exposed parts of the flue connections. The water which may be present in combination with the coal, or may happen to be on it by exposure to the weather, is sent over from the producer, but is or may be condensed in the flue. This is of the highest importance when fuels such as sawdust or refuse coal are used; and it is somewhat common to use scrubbers or condensing fixtures in the flue close to the producer, so that this great excess of water may be condensed out of the gas. Some of the later producers are built in a form nearly cylindrical, for greater convenience in the feeding of the coal and in the general maintenance of the whole in best working order. Blast is usually supplied to them by a steam-jet blowing fixture. It will be readily understood that all the nitrogen which enters with the atmospheric air into the interior of the producer remains unchanged, passing over into the furnace as an inseparable component part of the fuel supply. The action of the regenerative fixtures is such, however, that the nitrogen is heated before entering the furnaces, and hence by its presence it exerts no such hurtful effect, by an absorption of the useful heat of the furnace, as is common and universal in the furnace which is fired direct.

Natural gas.—This valuable fuel forms the subject of a paper on pages 233 *et seq.* of "Mineral Resources of the United States, 1883 and 1884," and hence no mention need be made of it in this essay other than to call attention to the clearly marked differences, as shown in the table of analyses (p. 34), in the quality of the gas which have been observed.

days renders it needful to keep up something of a cupola plant in the Bessemer works for remelting it, in case there may be no general market outlet for it and the furnace managers do not choose to bank their furnaces for the Sundays. The fixtures needed for this special department of a Bessemer works for the transfer of the iron are simple, and the same in kind as those needed in other parts of the works. These are a track leading by the most practicable route from the furnace to the converter, a series of railroad ladle cars, and one or more locomotives. These cars are usually run close to the base of the blast furnace, so that they receive the metal with least possible loss of heat; and equally close to the nose of the converter, so that the iron may be poured into it without the intervention of a spout or runner of any kind.

Old steel rails and scrap.—In the early history of the Bessemer manufacture it was considered very doubtful whether the metal which was then urged upon the market in the form of new steel rails could ever be utilized, or even sold at all, when after some period of time, then quite uncertain and believed to be very long, it should be offered as a worn-out material. This metal was so wholly unlike the iron rail, which had nearly always been reworked without difficulty, that it was clearly found impossible to pile, reheat, and reroll it in the same way, although some very skillful efforts to do this are on record. The quantity of new steel rails thus made and sold even at this early time was so enormously in excess of any current requirements of crucible-steel melters for remelting, that quite an interesting field for speculation and study appeared. Fortunately the way was also opened, before any important accumulations had been gathered, for the utilization of the whole of this worn or disused material by the development of the open-hearth furnace. By means of this important ally of the steel melter not only all the old steel rails that are ever likely to come to it may be transformed into new ingots, but also an important variety of materials, good, indifferent, and oftentimes bad, are or may be remelted and reworked or so modified that they shall not only be salable but highly desirable for many purposes.

Some important secondary industries have been based upon the use of old steel rails, and on very general principles it is understood now, however obscure the outlook may have been years ago, that no metal so useful in the arts as this would long be permitted to lie unused when worn out, by whatever process it had been converted from the more crude state. It is clear that the limit of this secondary use of old steel rails by slitting and hammering or rolling them is to an important extent marked by the shape and sizes of the pieces thus obtained, which are not large, and in many cases by the quality of the metal itself, which, as already noted, is not high. At the same time it is true that a very important proportion of the consumption of steel in miscellaneous tools and bars is or may be of the general rail quality, and being thus

made in large quantities in the Bessemer converter it can be bought at prices which commend it to consumers who need a stiffness and endurance such as iron bars or tools do not possess unless made of much heavier weights.

Brief mention may be made of the difficulties encountered in the efforts, which have not yet ceased, to utilize this miscellaneous scrap steel material by piling and welding. Among these may be found the uncertainty in the exact uniformity of quality as dependent upon the carbon that may be present in it, and hence the heat at which the various parts of the mass may be properly welded. Next to this may be mentioned the certainty that some parts of such a mass will be overheated or melted, thus leading to serious oxidation and waste. Another objection is that so long urged against iron and the methods of working it, that the cinder due in part to the fusing of the rust and dirt on the material is almost infallibly caught and held fast in the mass when drawn out under the hammer or in the rolls. No useful result can be regularly obtained in such an operation and held to in current working except by the exercise of an amount of care and skill such as can be looked for in only a few workmen out of the many who would be likely to be called upon for such work. When this skill has been secured it is found that the cost of treatment by these indirect ways is far above the more rational process of direct fusion and recomposition, either in the crucible or the open-hearth furnace.

BASIC PROCESS.

General history.—For some years past it had been known that the presence of silicious materials in the lining of the Bessemer converter prevented the removal of phosphorus in the slag by reason of the stronger affinity of the phosphorus for the metal than for the slag at the high heat at which the process was completed. It was also known that if lime could be made into a practicable lining so that a reaction could be set up and maintained between it and the phosphorus in the iron, then this hurtful element could be so completely removed by absorption into the slag as to permit the use for steel making of considerable quantities of iron ore which had previously been wholly inadmissible. The use of this stronger material, lime, as a "base" for this desired chemical combination, has given the somewhat indeterminate name "basic" to this method of lining the converters. The records of the actual application of the lime lining and this general method of treatment are growing daily, and already indicate a degree of stability and permanence in the manufacture which are extremely promising. How far the marked differences in cost of labor between the foreign works and our own may tend to prevent the introduction of the process here is not yet wholly clear; nor is it yet a settled thing at what prices the lower grades of pig metal can be produced, the use of which alone can make the cost of the process practicable in other respects.

American study of the process.—Some very important studies have been made of this process in this country and skillful adaptations of existing plants have been effected for the purpose of simplifying the operations needful in the carrying on of the process, but only a moderate amount of work has been done in the actual use of the lime lining. That which was done proved to be thoroughly characteristic in kind as compared with the best results obtained in foreign works, and indicated clearly that when any pressing need shall be developed, the choice of American materials, the convenience of apparatus, and the ingenuity and faculty of management of American works will be found amply equal to the call likely to be made on them.

Details of process.—The lime lining is put into the converters in various ways, the material itself being first calcined and ground fine; it is then mixed with boiled tar to give it the needful plastic character, and is sometimes rammed into place in the usual way. In some cases this lime mixture is made into blocks and burned at a strong heat, these blocks being built into the lining as a wall. Usually the bottom of the converter is made up by ramming the lime into the proper outline on the removable section of the converter shell. Pins are set in this material so as to leave holes, after the mass has been baked at a high heat, for the admission of the blast, these holes through the solid material taking the place of the tuyeres in the older form of lining.

The most serious difficulty thus far encountered in the management of the process arises from the extremely friable character of this lining material. It is washed out of place very freely by the mechanical action of the iron and the blast and permits only a very brief duration of the bottoms and the more exposed parts of the lining. The nature of the reactions occurring in the process also requires the addition of 15 to 20 per cent. of burned lime to each heat of metal, all of which must be gotten rid of as a slag after it has served its purpose of taking up the phosphorus from the iron. The removal from the converter of the slag thus formed in large quantity from this lime put in during the process, and from the wasting of the lining, becomes a troublesome and somewhat costly part of the operation. The comparatively infusible nature of this slag also tends to a choking of the nose of the converter and to the chance of a thickening up of the lining in the less exposed parts. Thus it becomes quite needful, in order to secure the least cost of renewal and general repair of the linings, to take the whole converter bodily out of its trunnion section and to remove it to a convenient repair shop near at hand, a newly limed one being at once brought into the converting house so that the operations shall suffer the least possible delay.

Future needs.—The indications of all the work done in this way point to the need of establishing the manufacture in works built expressly for it, in order that the fullest economy of treatment in every detail may be secured. When this has been done, as schemed in the studies of new plant referred to, experience seems to show fully that even with the use

of materials differing in important respects the production of a metal can be continuously maintained which shall fully meet all technical requirements, and in some conditions of the market the commercial limitations of cost, which at present so completely shut it out. It is said that the proportion of American ores which are available in their comparative degree of freedom from phosphorus for the earlier or "acid" process in the converter is fully three times as great as that of the English ores. The proportion of the entire production of American ore which is thus suitable for use is said to be about 36 per cent., while the proportion of English ore for the same purpose is about 12 per cent. of the whole amount raised. These differences are in themselves of the highest importance, as indicating the call which may be likely to be made for the use of this process in different parts of the world.

Use in open-hearth furnace.—Although the metal thus made in the Bessemer converter by the basic process has been largely devoted to the finer grades of finished product, yet the adaptation of the special materials of the lime lining to the open-hearth furnace and the processes carried on in it have called for and have received the most careful attention. This is particularly desirable, as the supply of heat and the control of the temperature of the metal in the open-hearth furnace are entirely independent of the nature of the process and of the metal under treatment. It thus becomes a much simpler matter to deal with the excessive quantities of slag sometimes present by tapping it out of the furnace repeatedly during the continuance of the process. Thus the phosphorus which may have entered into combination with the slag is absolutely removed from the furnace beyond the possibility of the reabsorption by the metal, which has sometimes taken place at the latest stages of the process. This adaptation of the open-hearth furnace cannot justly be said to have advanced very far as yet in the obtaining of clearly marked commercial results. The roofs of these furnaces appear still to require the use of silica brick, the lime blocks being too friable for such service, and some trouble has been found in the wasting of this side wall and roof materlai at the line of joining with the lime of the bottom. Some relief in this particular has been obtained by the use of, a layer or course of blocks of an extremely refractory iron ore at this point. The repairs of the roof and side walls of an open-hearth furnace are at best somewhat expensive work, and hence any lessened duration of their life due to such causes must add materially to the cost of the basic process when carried on in this furnace.

Analyses.—Very extensive series of analyses and other examinations of the materials used in this basic process have been made from the very first. The selection from these which is given herewith may fairly be taken as showing approximately the means used and the results obtained in ordinary conditions of working, both in this country and abroad.

Acid and basic linings compared.

	Acid or older lining.	Basic lining.
	Per cent.	*Per cent.*
Silica	91	12
Alumina	6	4
Lime	1	50
Magnesia	....	31
Oxide of iron	2	3
	100	100

Metals used and produced in the basic process in the Bessemer converter.

	Pig metal.		Rail steel.	
	Acid.	Basic.	Acid.	Basic.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Carbon	3.80	3.35	.35	.46
Silicon	2.10	1.30	.06	Trace.
Manganese	.75	.60	1.11	1.18
Sulphur	.10	.15	.06	.05
Phosphorus	.09	1.75	.05	.06

The "washing" process.—A considerable degree of attention has been given in France and Germany to a so-called "washing" process for pig metal containing a sufficiently large percentage of phosphorus to render it undesirable or wholly unfit for use in the open-hearth furnace. This process consists in the treatment of the pig metal, usually in a gas-heated revolving furnace, in contact with a lining or heavy fettling of iron ore. At the comparatively low temperature of the melting point of pig metal it becomes possible to form and to maintain a combination of the phosphorus in the pig with the oxygen of the iron-ore lining of the furnace, and the metallic iron thus reduced from the lining is added to the metal under treatment. This is not unlike the refining process so long carried on in the common puddling furnace, in which some of the purest wrought irons ever known have been produced. Some careful thought has been given in this country to this subject of "washing" pig metal, but it is not yet clear whether the three chief points of importance have been fully determined, viz, the kinds of pig that may most usefully be employed, the cost of the process when carried on continuously, and also the uses to which with real advantage the resulting metal may be put. It would appear that this process should be managed as an adjunct to one or the other of two already in actual use, either to the blast furnace, taking the metal from it direct into the washing furnace, or to the open-hearth furnace, delivering the washed metal to it while still in the melted state. The results obtained in skillful hands in the dephosphorization of pig metal by the use of this process have been very complete and satisfactory in a technical sense. Metal

containing .8 of 1 per cent. of phosphorus has been washed or refined so that the metal run out from the furnace has held less than .15 of 1 per cent.

APPARATUS.

Ladles.—The ladles used in the steel works are circular or slightly oval in outline, and vary in size from those which can take simply the product of a 3-ton furnace up to such as will hold a 10-ton heat from a Bessemer converter, and so onward to those of such substantial capacity that they can contain 25 or 35 tons or more at a single heat. The construction is almost always the same, the material of the ladle shell being a heavy plate iron and the lining a refractory mixture of sand and loam put in slightly dampened so as to pack well against the sides and bottom of the ladle. In some cases bricks are laid on the bottom of the ladle to resist more perfectly the heavy fall of the stream of metal, which sometimes runs from a spout 6 feet or more above the bottom of the ladle. The casting ladle in which the steel is received from the furnace or the converter is usually set in a cradle which rests on the beams of the ladle crane. Trunnions are riveted to the ladle so that it may be swung slightly to suit the exact position of the molds, or so that it may be tipped completely over to pour out the slag or other débris which may remain after the steel has been run out.

Ladle crane.—This is made up of a ram acted upon by water pressure, and a pair of beams with braces, on which the ladle rests. A vertical motion of the whole is thus provided for and a smaller hydraulic cylinder is usually set on the beams, by which a motion can be given in and out in a radial direction to the ladle as it rests on the crane beams. A handwheel and worm are sometimes fitted, by which a slight rotary motion can be given to the ladle trunnion. In some of these cranes, which are used not only for handling the steel but also for transferring the pig metal from the cupola to the converter in the Bessemer works, the ladle hangs beneath the beams of the ladle crane. In this case another small hydraulic cylinder is added, by which the transfer ladle with the melted pig iron is tipped so that its contents are poured into the nose of the converter. Usually the control of all of the motions of the ladle crane which depend upon the water pressure is assigned to the men on a gallery, from which the needful view of the working of every part can be obtained.

Nozzle and stopper.—In the bottom of the ladle a firebrick nozzle is set in the lining, through which the metal is run into the molds. Into this nozzle a stopper is fitted made of a clay-plumbago mixture and fastened to the end of a heavy rod which extends upward and out over the side of the ladle to a lever attachment provided for lifting it. This stopper rod is protected along the part that reaches through the melted metal in the ladle by a casing of loam and sand molded upon it and dried. The ladle is brought to each mold in its turn, the stopper being lifted and dropped again as required in casting the steel.

Molds.—These are set in a circle such as shall suit the radius of the ladle crane and near the outer circumference of the casting pit. This pit is usually 3 feet deep, and extends round to and under the converters or close up against them. In some cases this pit is dispensed with, all the operations being carried out on the general floor level of the works, but the convenience of working usually requires that the molds shall be sunk part of their depth in a pit. Safety from the rush of metal which sometimes occurs in the spilling of steel also suggests the desirableness of confining it in the pit, in which, at the moment of casting, no one need be standing in the way. The molds are heavy iron boxes of such size as shall suit the ingots called for and from 2½ to 3½ inches thick. They stand on iron plates or blocks on which the steel strikes as it runs from the nozzle in the ladle. For small ingots the molds are often made in halves and securely banded together. In such cases the ingots are made with parallel sides and could not be gotten out if the molds were made solid or in one piece. For all ingots of large sizes the molds are made solid and are tapered enough in outline to permit the ingots to drop out as soon as they have slightly cooled. As soon as the molds have been lifted off from the ingots they are sometimes laid on cars at a very dull red heat and hauled out of the converting house to cool, others being at the same time brought in after cooling. In some cases the molds are showered with water, the object aimed at being the prevention of the cutting or roughening of the surface of the mold by the melted steel. This is the more rapid in proportion to the temperature of the mold at the moment of casting. When the molds have thus become somewhat roughened, the ingots may fail to drop out, and in this case the ingot and mold are lifted upon the frame of a massive hydraulic press, by which the ingot is forced out. It can then go forward at once in its turn to the rolling department with the least possible loss of heat. The molds are usually made of an iron which is fit for making steel, so that when they must finally be broken up the metal is sent at once to the melting furnaces and thus disposed of.

Except in a few cases the steel is always run in at the top of the mold. Many trials have been made of methods of bottom casting, but the expense of providing properly for it has prevented their extended use except for ingots in which special care needs to be taken to secure and to preserve the utmost uniformity of structure, as in plates and similar work, and sometimes for those of quite small size.

STEAM MACHINERY.

The steam machinery and plant of the steel manufacture comprise the boilers, the blowing engines, and the rolling-mill engines as the chief items, and to these may be added for the sake of completeness the extensive series of smaller engines and pumps found in every works, whether large or small.

Boilers.—These are of all kinds, according to the general preference which is so marked in some districts, or as determined by the more or less clearly defined choice of the manager by whom they may have been selected. These differences of practice it is impossible to reconcile, and no brief study of the subject can be specially useful unless directed to the points clearly established by long experience among prudent men. The fuel supplied for use at the boilers is often of a low grade and hence the efficiency is apt to be low. This leads to an important tendency to irregularity of pressure of steam, and this still further to a danger of loss of speed in the blowing and rolling-mill engines. These difficulties are surmounted in some cases by the use of prime fuels only and in others by the use of more boilers fired with the cheaper fuel and urged by artificial draft or blast under the grates. Some recognize fully the value in this rolling-mill line of service, with its extremely intermittent calls for steam, of boilers with an unusually large water capacity, so that there shall be thus stored up in the water a reserve supply of heat ready for transformation into steam at the very short notice usually given in these kinds of work. The fuels delivered at the boilers sometimes change unawares, in the water or the ash contained in them; and as it is of vital importance, as already noted, that speed in the machinery should be maintained, these reserve limits of heating surface and water capacity are worthy of the highest consideration they have ever received.

The boilers in steel works are at the present day almost exclusively fired with coal. In the blast-furnace plant the waste gas is burned under them and in some instances Siemens producer gas has been used in an experimental way. Within the limits of the "natural gas" belt that remarkable fuel has been largely used under boilers with great economy of labor and with the best promise in respect to current repairs of all the parts involved. Before the use of the regenerative furnace for reheating had become so common, many boilers were fired by the application of the waste gas from the numerous coal-fired heating furnaces. This use of waste heat is an economy of the truest type, for a boiler may be very correctly spoken of as a "regenerator," or a device for the storing and the transformation into useful effect of the heat which passes beneath or through it. As the non-regenerative furnace which supplies this waste heat to such boilers is fired direct with coal, there must exist in connection with its use the tendency to oxidation, or cutting and wasting by the flame, from which the gas-fired furnace may be kept so completely free.

Blowing engines.—The most recent practice in the design of these engines tends to a slight increase in speed. This is the more admissible in view of the adoption of an increased weight of parts and because of important changes shown in the type of framing used in some of the engines. Most of these machines, as used for Bessemer converters, are of the upright type, with shaft and flywheel set close down upon

the foundation at or near the floor level. The steam cylinder stands above the shaft and the blowing cylinder is placed still higher up and directly above the steam cylinder, so that both of the piston rods are connected directly to the cross head in the same vertical line. In some of the older engines the steam cylinder is partly inclosed by the side frames, upon the top of which is placed the blowing cylinder. In these engines the cross head is put in above the steam cylinder, and from each end of it a connecting rod reaches down outside of the flywheel to a crank pin which is set in the wheel hub

In some of the newest engines in which the attempt is made to secure a higher degree of economy than had been practicable in earlier forms, the Reynolds-Corliss type of gear for steam distribution has been introduced with important and characteristic results. In general workmanship these Bessemer blowing engines have always been kept to a good standard, as the work they do is hard in kind and must be done sharply when it is called for at the short intervals which separate the "heats."

In their details of valves the blowing cylinders have undergone important changes since the high pressures for this service were first called for, nearly thirty years ago. The best results are found to be obtained in the use of a large number of quite small solid metal valves with a spring attached to each, so as to insure prompt closing. The inlet and outlet valves are set either on the cylinder head or so as to open to a narrow belt at the end of the cylinder, the closest limit of space only being allowed in the clearance thus given.

Cupola blower.—For the cupolas two types of blowing machinery are used, the high-speed "fan" blower and the low-speed "paddle-wheel" type. Both give excellent results in the efficiency of the action of the furnaces they supply, and the workmanship of the best specimens of both kinds is such as to secure great durability.

Rolling-mill engines.—Reference is made in another place to these engines as specially related to the roll trains to which they belong. So far as their character as steam-consuming machines is concerned, it may be said, generally, that the work done by nearly all the larger ones is heavy and subject at the shortest notice to the widest variations. That is, the work done by the engine, the flywheel being for the moment considered as a part of it, may vary within the space of one or two seconds of time from 75 or 100 horse power up to 600 or even 800, either upward or downward, as the work of rolling may be off or on the rolls. This change, of greater or less degree, may take place ten to fifteen times per minute with but brief cessation throughout each entire week, and it is obvious that there is needed an automatic apparatus of the most exact description which shall correctly measure the consumption of steam at each instant, as suited to the work then doing, if a rigid economy is to be maintained and if the needful uniformity of speed is to be preserved. Not only is this true, but the strength of all the parts involved, from the bottom of the foundation upward, including all the

trifling details of these automatic fixtures, must be such as shall stand wholly beyond the destructive effect of shocks due to the derangements of working sometimes encountered. Every effort is made to interpose breaking pieces between the rolls, in which these shocks generally originate, and the more costly parts of the engine, but even these sometimes fail to ward off a blow of serious weight. These needs of exact adjustment to work done have been very fully met, and so also have been the demands made upon builders for durable engines. Quite small sizes of engines are furnished with all needful fixtures of these kinds and they run with great accuracy and economy.

HYDRAULIC MACHINERY.

General character.—This department of a fully equipped steel works may justly be said to be to it, in the completeness and convenience of its working, what the hand and arm are to the human body. Nearly all the moving and lifting of the heavy masses, both hot and cold, which must be dealt with are thus accomplished, and little more can be looked for or desired than the present efficiency of the working of well planned fixtures of this kind.

The general scheme of the present system of hydraulic machinery as adapted to use in a steel converting house is very largely the design of Bessemer himself, who recognized at the first the entire impracticability of handling promptly or at all by older methods the masses of metal with which he proposed to deal. Some important improvements in details of outline and construction have been made in later years and by many hands, but the prime requirements of simplicity and concentration of parts were fully provided for in the first fixtures that were erected twenty-five years ago.

Steam pump.—The pump which distributes the water to the different parts of the hydraulic machinery is usually, in this country, of the "duplex" type, with compound steam cylinders and condensing apparatus. Some of these pumps are 21 inches and 36 inches diameter by 36 inches stroke on the steam end and 9½ inches diameter with the same stroke of plunger on the water end. This duplex pump has been found to be especially adapted to this kind of work, the forcing of water under high pressure, since from the nature of the motion of the pump each plunger comes to a state of rest for a moment until the valves can seat themselves quietly, and without shock in the body of water which had been in motion.

In some cases a series of plunger pumps placed side by side have been used, deriving their motion from a double or triple-throw crank shaft in which each crank is set a fraction in advance of the one next behind it. Thus the motion of the series of plungers is continuous in an important sense. The jar, if any, due to the cessation of motion of the plunger is the least possible, as one only comes to rest at any one instant. Some

have held that a crank shaft and flywheel motion is preferable for such work, permitting the more economical use of steam in the cylinder of the engine; but, as the compound duplex pumps work with an expenditure for feed water of about 26 pounds per hour for each indicated horse power, there is no large room left for such preference in the lines of work thus far undertaken. From the pump the water passes into the general circulation of the works, either through the accumulator itself or through a system of pipes in free communication with it, so that the full hydrostatic pressure shall be constantly maintained.

Accumulator.—This acts to a certain extent as a reserve supply, so far as its contents go; but it fills also the more important office of determining and maintaining the pressure upon the whole system. It consists of a cylinder within which works vertically a plunger, packed watertight at the upper end, 18 inches diameter by 12 feet stroke being a common size. On the upper end of the plunger, as it extends upward above the top of the cylinder, is fitted a plate-iron box. This is filled with gravel or any convenient material which shall be, in total weight resting on the plunger, sufficient to correspond to the pressure per square inch required in the area beneath the plunger or the standard called for in the general scheme of the works. This is usually from 300 to 350 pounds per square inch in the American works.

Two principal methods of doing the work have been employed, or rather two motions only need to be provided for, one in a right line, as in a crane, which must lift a load vertically, and the other a rotary motion, as of the converter.

Hydraulic crane.—The first is provided for by the use of a crane cylinder or column set on a suitable pier or foundation, within which is placed a ram or plunger of such diameter as shall correspond to the weight to be lifted. To the head of this ram is attached a framing made up of a vertical mast, with suitable braces, which reaches up into the roof for a top support, and a pair of iron beams which reach out laterally 20 to 25 feet, or as far as may be needed to cover the space for which the crane is required. On these beams a trolley runs from which a chain hangs down far enough to be reached from the floor. The weight to be lifted is attached to this chain by suitable tongs or slings, and upon the admission of the water to the cylinder of the crane the ram rises, carrying with it the mast and beam framework and also the load which may have been attached. The crane is in most cases swung round by a hand line fastened to the outer end of the beams and the load is pushed in or out on these beams by hand also.

Double-acting cylinder.—The second or rotary motion is effected by the use of a cylinder with a piston and rod, to which is attached a toothed rack of suitable length. This rack engages with a gear of such diameter that the needful arc of rotation shall be provided for. Thus, by admitting the water upon one side or the other of the piston the rotation is effected.

Water-pressure engines.—In a few cases the use of reciprocating engines connected to a crank shaft has been found desirable for the rotation of such machinery, to be actuated by the same water pressure, but it has not been common in any of the American works.

Direct lifts.—For long lifts the use of cylinders and plungers of the full length called for have been somewhat common. In some cases the use of chains or wire ropes has been preferred, in combination with a shorter cylinder and multiplying wheels, but in every case the chief requirement of freedom from derangement or any need of repair, even in the hands of heedless workmen, is the thing to be assured.

Hand valves.—It is usual to gather the valves by which the motion of these hydraulic fixtures is controlled in one place, so that the men who oversee or actually do this part of the work of the house shall have the whole as fully under control as possible. This is done by placing the valves on a central supply box, which is fed with water from the pressure pump, and from each valve a pipe is led to the crane or other hydraulic cylinder to which it may be assigned. The workmen usually stand upon an elevated platform directly above these water valves, and to this point are brought also the valves which control the supply of air to the converter.

Traveling cranes.—The use of power traveling cranes and of ordinary cranes worked by steam engines has been urged for some of these operations, but it is far from clear whether such comparatively intricate kinds of machinery would endure the exposure to dust and to careless treatment to which they would be subject.. To supply the water under pressure economically requires an engine of high grade, but this can always be suitably housed and skillfully taken care of. After this supply has been provided for it is difficult to see what just call there can be for any other than the simplest type of apparatus for this whole range of operations throughout the entire manufacture.

FINISHING MACHINERY.

Chief requirements.—It is not far from the truth to say that the prime qualities found in all successful finishing machinery for steel are rugged, massive proportion of parts and a degree of simplicity of mechanism which borders almost upon crudeness. Differences in first cost in favor of any probable reduction in dead weight wholly disappear, as do also any savings in fuel due to the use of excessive refinements of adjustment in steam machinery, before the possibilities of breakdowns or detentions of whatever degree that crowd themselves upon every manager. Experience has most conclusively shown that in no other way can those exigencies be met which are likely to be encountered in nearly every department of steel working than by a use of material so lavish in quantity as to appear absurd to one who sees it working under what appear to be normal conditions. The real fact is that the limit which

must be held to by the constructor as normal is the stress due to an accidental fouling of the machinery when running at full speed, and this, sooner or later, is encountered in all rolling mills.

Separate grouping.—The first result to which some years ago these possibilities of breakage led, even while iron was still the principal metal dealt with, was the entire separation of each part or item in the rolling and finishing machinery from every other. At an early day it was quite common to find one central engine driving an extensive series of roll trains, shears, and kindred machines spread out in some cases over considerable areas in the mill buildings. Any derangement of any one of these machines, or even of some trifling detail of the connections, was necessarily felt in the stoppage of the entire system, and in the loss of product until the injury was repaired or the derangement adjusted, or at least until the broken-down fraction could be disconnected, leaving the other parts to go on. At the present day in the best works every part or individual item of the machinery is detached from the rest, especially in respect to its motive power. In fact, some of the more complex machines have two or three engines in immediate connection with them, so that there shall be the least possible number of parts, such as connecting shafts or links, which shall be liable to give out in any way and thus to cause detention. It is somewhat difficult to make a list of these items of machinery in the rolling department which shall be strictly consecutive in the order in which the metal passes through them. Some of these items are so related one to another that both should be named in the same connection, although the actual work done by one lies along quite a different path from that of its fellow.

Engines.—The engines used in steel rolling and finishing are of various types and sizes, ranging in dimensions of cylinder from about 8 inches diameter by 10 inches stroke up to 40 inches diameter by 60 inches stroke. They run at all speeds, from about two hundred revolutions per minute for the smallest, to ninety and sometimes less, for the largest. A majority of them are fitted with the usual shaft and flywheel common in other lines of manufacture, both the shaft and the wheel being, however, of most generous dimensions and weight, reaching sometimes the substantial total of 70 to 80 tons if taken together. Some of these engines are coupled direct to the roll trains through the coupling "spindle" and a "box," the latter being usually reduced to the lowest reserve of strength which shall suffice to do the current work of the mill. It thus becomes a breaking piece, which, by its breaking on the instant of the occurrence of a wrecking stress at any point in the mill, shall insure the instantaneous stopping of the rolls before the momentum of the flywheel can damage or destroy any part which might prove a hundredfold more costly in repair than the breaking box itself.

Belt connections.—Some engines are connected to their work by belts leading from a pulley on the crank shaft to a similar one, though usually it is much smaller, on a counter shaft. To the end of this the driv-

ing spindle is connected, as before mentioned. These belt connections are usually employed when the rolls must be run at comparatively high speed, and a well-planned arrangement of this kind leaves very little to be desired in smoothness of operation and endurance of parts.

Reversing engines.—Some engines, designed more particularly for the latest methods of rail rolling, are built as reversing engines, without any flywheel and with two cylinders, which are coupled to cranks placed at right angles with each other on the main shaft, so that the continuity of the motion of the engine can be fully maintained even under the heavy load of the rolling. The reversing engines are coupled to their roll trains direct from the crank shaft in some cases, though the preference seems rather to lie in favor of the use of a counter shaft with very massive gearing between it and the crank shaft of the engine. This latter arrangement permits the use of "overhung" crank pins and obviates the necessity for the use of a shaft with "return" cranks. These "return-crank" shafts in large sizes, whether cut out of the solid metal or made as "built-up" cranks, are very costly if not dangerous, and are rarely adopted, except upon compulsion, as on board steamships, where some considerations must be sacrificed to compactness of outline. Reversing engines have been common abroad for some time past, but here they have been brought into important use only within a very few years. The most careful study has been devoted to some of these to secure the fullest simplicity of design by which strength and accessibility in every part shall be insured and so that the highest degree of economy in working shall be reached consistent with entire durability in the automatic or similar fixtures upon which the control of the steam supply may depend. The use of the reversing engine in rolling rails has usually been joined with the practice of rolling in double and even in quadruple lengths. This use of long and heavy blooms in the rail mill has been possible in this case, as the piece in this method of rolling does not have to be lifted as in the three-high mill. In this practice of rolling pieces of extreme length, 120 to 125 feet, it becomes possible to considerably increase the speed at which the piece passes through the rolls after it has once entered, so that some advantage is gained in that way. As the full load is on the engine, in this case of the use of long pieces, for a larger fraction of the time, there is some room for a more economical use of the steam than when, with short pieces, the work is done in heavy spurts, and hence with less possibility of expansive working. An objection to the use of the reversing engine is the greater loss due to the friction of additional parts and to the use of steam in two cylinders instead of in one only. As an offset to these considerations may be placed the loss in the friction due to the great weight of the flywheel, which the reversing engine does not require. A few of these engines have been made with compound cylinders and condensing apparatus, and these when built after well-approved designs have been run with excellent results in durability and high economy.

The two-high roll train.—This is the simplest form of rolling mill, and for many years it alone served in this branch of the manufacture of iron. The train as a whole stands on a massive foundation, usually built as a part of the engine pier or walls. A bed plate is bolted to the foundation and on this stand the "housings" or heavy frames in which the rolls are to be placed. Within these housings are fitted boxes which hold firmly, although permitting adjustment, the turned necks of the rolls as they revolve. In the "two-high" train two rolls only are used, one above the other. The work of rolling is done as the piece passes between the rolls, the gradual reduction in the thickness or other dimension of the bar being due to the reduced area of the grooves which are turned in the surface of the rolls, and through which, one after another, the bar is passed. The top roll is held down, against the tendency of the rolling operation to lift it, by a substantial screw set in the top of the housing. By slackening this screw, the distance between the two rolls may be varied at pleasure, within obvious limits, and hence the sizes in respect of thickness or similar dimension of all pieces rolled in the mill can be readily adjusted. The boxes which hold the roll necks have also lesser adjustments to compensate for wear and various conveniences for keeping them clean while at work and for lubrication. Motion is given to one of these rolls directly from the engine or the counter shaft through the spindle referred to, a pinion, and a second spindle. This pinion, a heavy-toothed gear or wheel, is held in housings, and close above it and engaging with it is placed a second pinion. The upper pinion is coupled to the top roll by a spindle and boxes, so that each roll is driven independently of the other through the pinions from the engine. The piece passes through the rolls, being reduced by the difference in area already referred to, between any one groove and the preceding groove. It is then passed back over the top of the upper roll to the front side of the rolls and is again sent through between them. In this method of working it will be seen that, strictly speaking, the roll train is doing useful work only about one-half of the time, although the general expense of maintaining the whole apparatus of the mill remains unchanged.

Three-high mill.—This led many years ago to the use of the "three-high" mill, which is made up, as its name suggests, by adding a third roll to the combination just described. A third pinion was also put in and the engine connection made with the middle pinion of the group. By this means it became possible to do useful work on the bar during its movement in both directions, the upper set of grooves being so proportioned to those below as to work correctly with them in the reduction required. Thus the product of the roll train was at once increased from 60 to 80 per cent., with an outlay for the additional fixtures of trifling amount. A very large fraction of the whole production of iron and steel in the form of bars of medium and light weights, including rails and

most structural shapes, is now rolled in three-high trains of this general description.

Feeding tables for three-high mills.—In connection with the three-high blooming mill used for rail ingots, some very complete lifting fixtures were devised some years ago and they have been perfected with the added experience of their use in many hands. These consist of a series of rollers on each side of the train set in substantial frames. The roller tables, thus made up, rest on lifting rods reaching down beneath the floor, where they are coupled to lifting arms keyed to a series of substantial shafts. These shafts are rotated far enough by a hydraulic cylinder to lift vertically the tables thus connected to them a distance corresponding to the height at which the groove between the upper rolls stands above the lower groove. The rollers on the tables are driven in either direction by a small reversing engine, so that the ingot may be fed into the roll grooves from each side of the train. The ingot is delivered on the first table from the furnace and is at once fed into the lower groove by starting the table engine. After the bloom has passed through the lower groove it is received on the second table on the back of the train. Both of the tables are then raised and by the roller engine the bloom is fed into the upper groove, from which it is received upon the first table, which had been raised at the same moment with the bloom itself on the second table. While lying on the first table the bloom is now lowered and is again fed into the rolls. It is needful that the bloom during the rolling should be repeatedly turned up on its edge, so as to be equally reduced on all four sides. To do this a line of horns is placed between the rollers of the first table so fixed on a frame on the foundation beneath that the horns can travel across the length of the bloom. As the bloom is descending on the first table these horns are run forward by a hydraulic cylinder so as to catch just beneath the edge of one side of the bloom, and as the table is still farther lowered, the bloom, being thus caught along one side, is tumbled over as required. The line of horns can be so traversed across the front of the rolls as to turn in this same way the bloom as it issues from either of the four or five roll grooves. The control of all these fixtures is usually given to one man, who can so manage the combined motions of the bloom in its passing through the roll-grooves, the raising and lowering of the tables, the turning over and pushing from side to side, and the feeding motion of the table rollers, that the ingot shall appear of its own will to move through each step of the process in its turn.

Some ingenious contrivances have recently been adapted to the handling of the pieces in the working of the three-high train for rail rolling, chiefly in connection with the transfer of the bloom from one groove to another. This has long been done by "hooks" or levers suspended from above, and handled by men at considerable cost. Some labor is also needed in the ordinary ways of working in guiding the bloom accurately as it is swung on the hooks. All this labor is likely to be saved

by the use of the guide bars and roller tables fitted to the most improved mills.

The two-high mill in its more primitive form has been retained in use chiefly in cases where a few bars only of any given size are likely to be called for at a time and hence in which the greater cost of changing the rolls and adjusting the three-high fixtures would not be found admissible. A wide variety of smaller fixtures and hand tools are used around these roll trains, such as tongs for holding and guiding the pieces, hooks and bars for lifting or carrying them from one groove in the rolls to the next. Generally speaking the whole equipment of roll trains in a modern rolling mill is based upon the outline thus described. The special forms of mill and the important contrivances found in them, by which they are made to do special and sometimes intricate work, are numerous. Only a part of these come properly within the scope of this paper and these will be briefly described.

The two-high reversing mill.—This has been used abroad for many years, but no large amount of work has been done with it here until a comparatively recent date. In these mills the engine in a very few cases has been of the flywheel type, and the change of motion has been effected by the use of substantial friction clutches, with intermediate gearing between the engine and the train. This kind of reversing apparatus has been found to be far from durable in its operation, although it has been made to do a good deal of heavy work. Great relief had been found, however, in doing some kinds of work in these trains by the use of the reversing engine referred to. This first became common abroad in order that the existing two-high fixtures might be utilized, and because of a general conservatism, which held that the two-high mill was just the thing. In this country the three-high mill from the first found more favor than abroad, and hence the importance of a reversing mill was less strongly felt.

In the rolling of rails after the ingot has been drawn from the soaking pit or the reheating furnace, the current practice varies somewhat at different works. In some cases, following still the earliest methods, the long piece, as it leaves the blooming mill, is cut in a shear or under a hammer into several pieces, each long enough to make one rail. These short blooms are then transferred, sometimes over a considerable distance, to a second furnace; are reheated and then rolled out into finished rails. In later methods, the blooms are cut and rolled out without a reheating. In the most recent practice, with the use of reversing trains and engines, the full-length bloom, usually long enough for four rails, is transferred at once from the blooming mill to the rail mill and rolled out into a single piece 125 to 130 feet long. This is cut into the standard lengths called for, and the rails are sent forward and finished in the usual way. Some extremely important savings have been made in the cost of production by these more direct methods of working, in the reduction in labor of heating, in the waste in the fur-

nace, and in the reduced weight of metal in the crop ends which are sawed from the single-length rails and thrown aside for remelting.

Universal mill.—Probably the earliest important use of the reversing mill here was made in the rolling of very long plates, comparatively thin and narrow, for use in bridge building. These could not well be rolled in a three-high mill, and it was essential that they should be finished, whatever might be their width or thickness, with straight and square edges. This led at once to the contrivance of a form of the "universal" mill, in which the usual top and bottom rolls of the two-high mill were turned perfectly plain and straight on their faces and were fitted with a series of smaller vertical rolls so set as to bear against the edge of the piece as it moved back and forth between them. The top roll is raised sufficiently to admit the piece when brought from the heating furnace, and by suitable hand attachments it is screwed down by a small amount after each movement of the piece between the rolls. Thus by repeated reversings of the engine and rolls the plate or bar, of whatever width or thickness, was gradually rolled down to the size called for, and finished with straight edges and in any length up to 60 or 80 feet or more, according to the facilities for handling.

Carrying rollers.—It was found needful from the first to provide rollers on both the front and back of the train, so that the pieces should be properly supported and readily and promptly fed into the rolls after each reversing. These rollers are therefore set accurately in long frames on proper foundations, and are driven in either direction by a small independent reversing engine. After the rolling of each piece is finished it is left on the roller table until cooled enough to permit handling without distortion, and it is then dragged away. In some cases, when heavy bars are to be rolled in this way, it is needful that the vertical or "edging" rolls should themselves be driven, so that the bar may be compressed upon its edges more than can be possible when the only pressure exerted by these rolls is that due to the very slight "spread" of the piece as it is reduced in thickness. Sometimes the edging rolls are made adjustable laterally, so that the width of the bar may thus be more accurately controlled. Nearly all of the so-called eye bars for bridge work are rolled in mills of this type. Some special fixtures for opening and closing the rolls have been contrived, by means of which these bars have been rolled with the enlarged ends which are needed for the pin connections.

Reversing mills for steel.—As soon as the call became clearly defined for steel blooms in various sizes and lengths, it was found that some more perfect means for rolling the long pieces was needed than had existed in the three-high blooming mills used for rail-ingots. This led to the development of a two-high reversing mill of the most substantial construction, with engine and roller tables complete. In this it has been found practicable to roll, with great economy of time and labor, an ingot 14 inches by 14 inches by about 5 feet long into a bloom 4 by 4 inches

by about 60 to 70 feet long, or to any intermediate size whatever. This mill is made with shallow grooves in the rolls, so placed that the ingot shall be rolled flatways and then edgeways, the grooves being reduced in width toward one end of the roll, so that as the rolling progresses, the piece shall still be held somewhat firmly against the sides of the groove as it passes through. The successful use of this two-high blooming mill was so marked that it has found its way into use for rail blooms. One important detail of the handling of the ingots in the reversing mill is worthy of mention. It is that the weight of the piece does not need to be lifted at all. It has to be turned up on its edge, but the cost and the repairs of the carrying fixtures are greatly reduced.

Continuous mills.—The "continuous" type of rolling mill is also a very important addition to the general series of rolling machinery with which modern mills are provided. It first became recognized and successful abroad, but valuable advances have been made here in the general plan of construction and in the endless items of detail upon which so large a proportion, if not the whole, of the success of such machinery depends. In general terms, the construction of the continuous mill is such that the piece, 15 feet to 30 feet long to start with, is fed into a pair of rolls running at moderate speed. It then passes after this first reduction directly into a second set, placed close by and running at a higher speed, so that the piece shall travel as much faster through the second set than through the first as its area of cross section or size is less. The piece then goes on, passing directly from the groove in one set of rolls to the smaller groove in the next size, until it has been reduced to the size and shape called for. It is obvious that the grooves are carefully arranged, both in shape and area, so that the piece shall be taken up at once and properly reduced. It is also clear that great pains must be taken to see that the guides and pipes and other fixtures, by which the end of the piece is transferred from one groove to another, are perfect in shape and kept accurately in place. If the piece or "billet" is of the common size for this kind of work, 1¼ inches square, and the finished product or "rod" is five-sixteenths of an inch diameter, it will be seen that as it approaches the finished end of the series of rolls the rod must actually fly from one groove to the next at a very high velocity in order to keep out of the way of the parts which follow, even though the billet may be moving into the first set of rolls at quite a low speed. The whole train is usually so placed that the billet shall enter at once upon being drawn out of the door of the furnace, so that not more than a few inches of the length of the billet are exposed to cooling before it enters the rolls. The billet is thus drawn out of the furnace only as fast as it passes through the first set of rolls.

Belgian mill.—Another mill for doing the same kind of work in a way which may fairly be called continuous is the so-called "Belgian" mill. In this as first made the piece was passed repeatedly through a set of

rolls running rather slowly until it had been somewhat reduced and comparatively flexible. The end of the rod, upon issuing from the first groove in the second set of rolls, run at higher speed, is skillfully caught by a boy with tongs and put into the next groove. It is then caught and put forward again, and so on until the rod is rolling in six or seven sets of rolls all at the same time, these rolls forming parts of the same series and all running at the same speed. The "bight" or slack part of the rod between these different grooves lies on the floor of the mill in convolutions of the most striking character as the rod passes swiftly through them from one groove to the next. An important improvement even upon this method of doing this work, or rather a much-needed addition to it, has been made in the use of additional rolls of larger size and running more slowly. In this "Garrett" combination a 4-inch bloom is rolled at one heat in an 18-inch train to about $1\frac{1}{8}$ inches square. It then passes through a 12-inch set of rolls and then forward to two 9-inch trains. In these last two sets of rolls the piece is turned in and out in the manner already described. An important feature of this combination is also the use of four separate engines for driving the trains, so that each can be run at its own proper speed and with no chance of hindrance from any outside source. In all these high-speed rod mills, as soon as the end of the finished rod issues from the last set of rolls, it is caught and taken to a reel, upon which it is wound up and fastened together as a compact coil for use as required. The product of this last-named mill may be given as 80,000 pounds of rods .22 inch in diameter per turn of nine and one-half hours.

These forms of mills, which work more or less fully on the continuous plan, are more largely used for wire-rods than anything else; but adaptations of them are possible, and have been made, to the rolling of heavier rods and to the making of hoops and other light bands up to 3 or 4 inches in width.

In the rolling in these high-speed trains the detentions and losses of product by actual breakages and by imperfect working are now cut down to a very low figure. It becomes the more important that this should be so, as the speed of the machinery in doing such work is increased, for thus the cost rapidly increases, and hence the loss on any part of the product which may be interrupted and thrown back for remelting by any imperfect working of the machinery or by an actual breakage.

Plate mill.—Turning from this lighter class of machinery to the plate mill, it may be noted that the general type of the best modern examples is that of the three-high mill, with roller tables attached. The so-called "Lauth" combination is chiefly used, in which the middle roll of the group of three is much smaller than the others, the top and bottom rolls being in some cases 32 inches in diameter, while the middle roll is 20 inches. Two advantages attend the use of this combination of a small middle roll with larger top and bottom rolls. One is the

greater ease with which the reduction of the metal takes place in the rolling, and another, the less distance through which the plate as it is rolled must be lifted in order to return between the upper pair of rolls. The strength of the middle roll is found ample, even though it is of smaller size; for when the rolling is against its lower surface it bears over its whole length against the large upper roll, and in the same way against the lower roll when the plate is being rolled between the upper pair of rolls. The screws by which the rolls are moved and adjusted vertically are turned in the smaller mills usually by large hand-wheels. In the larger mills a belt connected to the engine shaft is sometimes used. In some a hydraulic cylinder and piston are fitted, and in others still a small reversing engine. The latest plate mills erected in this country are by far the most substantial pieces of machinery yet found in rolling-mill establishments. Plates 9 feet wide and of any required length can be rolled in several of these mills. The rolls themselves have usually been "chilled," so that they have a hard, smooth surface when turned. In some cases steel castings have been used for these rolls, although the absolute endurance of this metal in such lines of work has not been fully determined. There is no reason for supposing that the full limit of size in plates has yet been reached. It is possible that few shops, if any, in which plates are worked up into finished forms in boilers or any similar work, are prepared to handle in their own manufacture any size of plates at all approaching those which have been within the limit of the rolling-mill machinery for several years past. Great care is needed in the cooling of the plates that they shall not become buckled or warped. The plate-ingots are cast in nearly all sizes up to about 3 feet by 5 feet by 10 or 12 inches thick. This general requirement of steel working holds good in plate rolling, that an ingot should be reduced to about one-tenth its original thickness or cross section in order to develop its maximum strength.

The approximate weights of the principal parts of one of these large plate mills of the "Hemphill" pattern are as follows:

Parts.	Pounds.
Bed plate	37,000
Roll housing	51,000
Large pinion	14,000
Small pinion (steel)	8,300
Large roll, 115-inch face	29,000
Small roll, 115-inch face	12,000

The nominal diameters of the various sizes of roll trains range between 48 inches as an extreme downward to 8 inches, including between these extremes some ten or more intermediate sizes. These are used in rolling plates, blooms, rails, billets, bars, and rods, the preference for any exact size for a given purpose depending chiefly upon the individual preference of the manager. Rails are usually rolled in a train not

larger than 23 inches diameter, and bars 1½ inches diameter in a 12-inch train.

For bars and rods smaller than medium and full-sized rails the same general method of treatment after the rolling prevails. If bars are occasionally found crooked when cold they are straightened under a press or by hand, as may be needful. All these lighter forms of rolled bars are laid out for cooling on carefully leveled beds or floors, so that there may be as little chance as possible of twisting or bending in any way. For some purposes the call for exact straight bars is so rigid that an important fraction of the cost of such bars is the labor of straightening.

The shears and other secondary machines required for plates and bars are of the same general type as the rolling machinery itself, substantial and of simple design. These vary in size from those intended for snipping off the end of a rod one-half inch diameter, up to the massive shears for heavy steel plate, which will cut a plate 100 inches wide and 1 inch thick. Several of these large machines of the "Morgan" pattern are built in a very compact outline and weigh upwards of 70 tons.

Bloom shear.—The use of a shear for cutting hot steel blooms was almost forced upon managers of steel mills by the inability of the hammers to keep up with the increasing production of the works and by the large comparative cost of running them. It had long been a common thing to cut off miscellaneous bars and forgings at the hammer as they were finished, and as soon as ingots began to be made large enough for more than one rail the hammer was clearly the first and only thing thought of or available for use in cutting them. The strength needed in the parts of a shear and the power required to work it were little more than matters of conjecture, when, at length, the first one was undertaken. Actual trial showed, however, that even a 7 by 7-inch bloom, when at the ordinary heat called for in the best practice in rolling, required less power to cut it than was anticipated, and also that the dimensions of parts which were adopted in the design of the shear were sufficient for average conditions of work. Experience soon showed that cold pieces were likely to be put into the machine, and these proved, as might have been expected, too much for the endurance of some of the parts, substantial though they were. The first complete shear of this class was made with a horizontal movement for the knife, derived from an eccentric on a third-motion shaft. The machine was driven by an engine with heavy flywheel, geared direct in the ratio of about 12 to 1. The same type of machine continues in well approved use, although the parts subject to these stresses have been enlarged, until as a whole the weight of one of these machines has reached 50 tons.

Vertical shear.—With the development of the trade in general sizes of steel blooms and slabs there came a call for a form of heavy shear with a knife moving vertically, so that slabs 14 or 15 inches wide could be cut while lying flat on the shear bed. These had to be cut frequently into short pieces, so that this shear was set to run somewhat faster, and

a counterweight was added to lift the knife when the driving clutch had been thrown out of gear, so as to insure that when stopped the throat of the shear should always open.

General design.—These massive tools are good examples of the desirableness and even the necessity of designing them in such forms that the strength of the whole shall lie in a very few pieces, which simply bear upon each other instead of being held together by bolts or fastenings of any kind. The stresses which must occasionally be endured in such machines are so extreme that they can be successfully resisted only by the use of a frame or similar part of such massive dimensions and strength that the stress due to the current ordinary work shall be quite trifling when compared with it. These shears are always driven by independent engines, sometimes attached directly to the frame. The pieces are brought up to the shear and fed in as required, by a line of rollers leading from the roll train and in some cases driven by an engine set for the purpose. From the shear the miscellaneous blooms are removed to the stock yard or are sent out for immediate use elsewhere.

Chipping hammers.—In the earlier days of Bessemer-steel making the difficulty was encountered at times of the cracking of the blooms on the corners in hammering and rolling. This was due to various causes, most of which are now fully understood and guarded against; but the necessity then existed of cutting or chipping the cracks out of the bloom, lest, if permitted to remain, they should injure or wholly destroy the finished rail or other piece. For this purpose medium-sized hammers were erected in some of the works under which the chipping was done. These were also available for general use in making the numerous bars and other hand tools required. At the present day any such tendency to cracking is accepted on the instant as an indication that something is amiss in the earlier parts of the process of manufacture and remedies are quickly applied.

Hammer.—This has been from the very earliest days of steel making an important appliance, and for many purposes it still holds its place. For some kinds of steel the rolls are now preferred, as the reduction of the ingots can thus be effected at far less cost. The closest study has been devoted for many years to the improvement of the hammer, as to the general form which shall be given to it and in the details of material and workmanship. The best hammers now stand fully abreast with other high-class tools and machinery of the steel manufacture, and they are made in a wide variety of forms, so that all possible requirements of duty shall be fully met. The steam hammer is more subject to destructive shocks and stresses from the absolute nature of the work which it must do than almost any other of the machines of the steel manufacture, but the advance in the adaptation of the materials of which the hammer is made has been so complete that the endurance of the whole has been very greatly increased over what was common or even

noteworthy ten or fifteen years ago. Few of the hammers used in the United States exceed 8 tons in the weight of the ram or head by the fall of which the work is done. For very light work these heads weigh 150 or 200 pounds, and for making forgings of very substantial weight a head of 15 to 20 tons is called for. In the great works abroad there are a few hammers of extreme weight which have been erected for the forging of heavy guns and other similar work. Only a moderate amount of work has yet been done by these great tools, and experienced men differ in their judgment of the expediency of a pursuit of this line of research and practice, as contrasted with the use of a metal which shall be cast to a more exact outline, and subjected to treatment by fluid compression and by hydraulic forging apparatus.

In hammers of very large sizes the cost of the anvil and of the foundation becomes excessive, and of this fraction of the whole cost a very large proportion may be wholly saved if the work done by the hammer can be performed by these other means.

Hydraulic forging machinery.—This, in general idea, simply substitutes the quiet but intense pressure due to the use of a heavily loaded accumulator for the blow of a falling head or ram. This kind of machinery has been used on a limited scale and for light work for many years, but an entirely new call appears now to be made for machinery of this type of the most substantial description. The demand for heavy shafts and other similar pieces for industrial purposes has quite fully overtaken the limit of capacity of the hammers which are available for making them, and the call for heavy guns appears likely at no distant day to reach beyond the ability even of the gigantic hammers of which one or two have been set at work. There are the best reasons for believing that even the largest forging machine which is likely to be built will compare favorably with the hammer as a means of reducing the heavy ingots required in these more recent calls. Some experience has already been acquired in doing rather heavy work by means of hydraulic pressure, and thus far the indications seem to show that the cost of doing even the heaviest work and the excellence of the result when complete will be altogether in favor of this more quiet method of treatment. It is probable that the massive outlines of the machines which will eventually be called for will quite exceed present expectations which are held concerning them, but past experience in the contrivance and the construction of such apparatus indicates clearly that no well-defined call of this kind can possibly fail of a prompt and successful response. It is also probable that the quiet character of the work thus done will permit the location of the machine close to the door of the furnace, from which the ingot may be taken, or between two furnaces, so that the loss of heat in the ingot shall be the least possible.

SECONDARY MACHINES.

Transfer rollers.—The smaller machines in the rolling department of the steel manufacture may be briefly referred to. In rail mills the rail when finished is delivered to a series of rollers which may be driven in either direction, usually by a connection from the saw engine, and upon which the rail simply lies on its side. At intervals along this line of rollers are others which can be reversed and are so set on vertical axes and in pairs that the rail shall be gripped and firmly held by them in order that it may be thus sent forward promptly to the saws, and accurately set in front of them, to be cut off to the exact length called for. The saws are driven and placed in various ways, but usually so that they shall cut off the rail by being swung up against it laterally. The crop-ends are dragged away and piled up to await sale or use elsewhere in the works. By additional sets of gripping rollers the rail is now sent into the "cambering machine," by which the curvature is given to it which shall compensate for the greater contraction in the final cooling due to the excess of thickness in the head of the rail over that in the flange.

Cambering machine.—In this "Gustin" machine are two lines of rollers, set on vertical shafts, of three each, so placed that the rail passes between the lines. The middle roller of one line is adjusted laterally a trifle on one side, so that the rail in passing between it and the end-rollers of the opposite line is deflected and thus curved by an amount corresponding to the temperature at which the rail may leave the machine. These roller shafts are all driven by suitably geared connections from the saw engine. The machine as a whole can be very accurately adjusted, so that the rail when finally cooled shall be so straight as to require the least possible subsequent treatment. After passing through this machine it is delivered on the cooling bed, and is hauled away laterally out of the way of those which are to follow.

Straightening machine.—As soon as the rail has cooled it is passed beneath a straightening press, in which any curvature which may remain, due to the action of the cambering machine or to any other cause, is straightened.

Drills and punches.—The rail is then passed to the drilling machines at which the holes for the fish-plate connections at the ends are drilled, and to the punches, in which, if called for, the notches for spikes are cut near the ends, or for special end-fastenings which are sometimes required. They are then usually loaded at once on cars for shipment as required.

Farther advances.—It is probable that, aside from the question of the comparative economy in labor and repairs of different methods of rolling, there is less room for discussion and for improvement anywhere in the detail of the rail manufacture than in this finishing department, as it may very properly be called. All experience tends to show that the

structure of the steel, as a rolled metal, is completely determined before it becomes cold after rolling. Hence the necessity, if the rail has been thus rightly made and finished, that the character of the metal should not be impaired by any improper treatment when cold. The importance has been shown, by many trials, of so cambering the rail, and of handling it while cooling, that it shall be exactly straight when at length it has become fully cooled. In this way the value of a machine becomes quite apparent which can be accurately adjusted at short notice to suit the size of the rail and the change, if any, in the average heat at which the rolling is finished, and this leads to the least possible use of the cold straightening press on the rail. The action of this press in giving a permanent set to the rail in the cold straightening tends directly to a disturbance of the internal structure of the metal, and this has been clearly proved to be a source of weakness in the rail, for breakages in actual service have repeatedly been shown at points where the stroke of this press had left its mark. It does not yet appear how the use of this cold straightening process can be dispensed with. It is nearly the only remaining detail of the earliest method of manufacture which has survived unchanged, in spite of the obvious evil which attends it and the serious cost of doing the work.

For some years it was held that the holes near the ends of the rails for the fish-plate connections could be punched as well as not, so far as injury to the rail is concerned. Some makers have claimed that the punching is in itself a test of the fitness of the metal for use in rails; that is, that if it cracked or showed unusual resistance to the punch, it should be taken for granted that the metal was unfit for use for this purpose. This and some other similar considerations appear to have been waived by common consent in favor of drilling the holes, although punches are still used for the notches sometimes called for in the edges of the rail flange. So long as these are cut with rounded inner angles the strength of the rail does not appear to be impaired.

Experimental straightening machinery.—Several machines have been contrived, more or less automatic in their action, and great labor has been expended in the effort of adapting them to their work, for this cold straightening process; but the problem is an extremely difficult one. So far it does not appear possible to dispense with the use of the eye of a trained workman in detecting the crooked place in the rail, or with the exercise of his judgment in the working of the simple press, so that the rail when it leaves the machine shall be perfectly straight.

STEEL CASTINGS.

The use of steel as cast direct to exact outlines, in molds of sand or other suitable material, is an obvious outgrowth of the steel-melting process itself, and has been practiced with various degrees of success from a very early day. It has been made, within a few years only, of

actual service in a commercial sense to the engineering world, for nearly all the earlier efforts to produce a trustworthy metal cast to pattern were taken as incidental only, the product being used if it was found to be good enough and remelted with but little study if it was not.

An important part of the later development of this art is due to the systematic study and practice of French engineers and steel melters, upon whom a clearly defined call was made for the supply of material which should pass higher standards of testing than had been before required. This call was in fact for the creation, or at least the exact development, of a process for making uniformly and certainly a metal capable of enduring the extreme service called for in the use of shot and shell, and in general the full requirements likely to be specified in a complete series of artillery and ordnance supplies.

Difficulties encountered.—Reference will be made to some of the details of this part of the general manufacture of steel, but it may be said briefly at this point that those who have pursued the subject farthest and who have made the best absolute progress find themselves still hedged in with obscure difficulties. They are still unable to reduce completely the uncertainties of their methods, even those which they practice as being on the whole the ones most likely to prove effective in the solution of the general problem. At the same time it is true that the production of steel castings at such prices, both in respect to cost and selling value to the purchaser, as shall insure their continued use, is by far the most important phase of the steel manufacture at the present moment. It is also true that the indications of current processes of treatment of the metal and of the lines of study which have led up to present developments are such as point to the full realization of the anticipations of those who call for this high-grade metal and also of those who expect to make a profit in its manufacture.

Tests in the work.—These have been continuously made by some of the steel melters of the most exhaustive kinds, both physical and chemical, of the structure of the metals thus produced and of their composition. They have been carried on by the side of the furnace and the forge, as the most cautious experimenters have recognized the absolute need that tests should be made on the full-size scale of actual daily practice. The determinations of the laboratory apparatus, especially in questions involving treatment at high temperatures, do not show all the needful facts, however important these laboratory operations may be both as leading the way in new processes and as collateral at every step.

Character of earliest efforts.—As already noted, each steel-melting works has made trial, almost without exception, of imperfect methods of making castings, for use in their own current repairs of machinery, and in similar ways. Many of these castings when thus made proved to be nearly or quite useless, even though sooner or later the whole series of grades of metal were tried from gray pig iron up to a sharp *high-grade steel* and then to as mild a metal as could be run into a

molded outline in a fluid state. The same type or kind of difficulty remained in all, apart from the absolute temper or hardness of the metal—the tendency to form "blowholes" in the body of the casting, which prevented entirely the current sale of goods even if occasionally a good heat were made. This fact led rather to a general discouragement of the whole idea of making steel castings, and thus the progress actually made has been in the hands of comparatively a few, such as could see through, or made a way for seeing into, the confused network of indications afforded by the early trials thus made in numerous hands. The uncertainty of quality, even in the castings which were produced of sound texture, was so great that all the devices of annealing and tempering which had been common in the forging of steel were brought into use; but however important these supplementary operations, they are wholly subordinate to the chief requirement that the metal should first be uniformly and continually solid and free from blowholes.

Blowholes.—The formation of these cavities, which are not wholly unlike the bubbles secreted in masses of ice, is due to the collection of occluded gas liberated from the minute interstices of the metal in the gradual solidifying of the mass of the ingot. All metals possess to some extent the power of absorbing and retaining gases in substantially the same way that water is known to hold them. Some of these metals, as steel, appear to hold or retain the gas less firmly in the solid or cold state than when in a state of fusion. Hence, as the steel crystallizes and cools, important quantities of gas are released, and some of it finds its way out of the ingot through the side crust of metal which forms against the shell of the ingot mold and some by an actual bursting or crowding up to the top through the liquid or soft steel in the center of the ingot. Other particles of gas remain fixed in the bubble-like cavities just beneath the shell of the ingot, and in some cases they are so numerous and widespread as to transform the ingot nearly into a honeycomb.

Methods of prevention.—Two methods thus far appear to be available for preventing this loss of strength in castings due to the existence of these blowholes. One is to prevent the liberation of the gas which thus divides the particles of the metal, and the other is to compel, by very heavy pressure upon the fluid metal as it solidifies, the complete diffusion of this tendency to secretion throughout the entire mass, so that whatever secretion of gas does occur shall be in the most minute particles or cavities, such, in fact, as shall not differ from the molecular interstices themselves.

Use of silicon.—It would seem that the discovery was made, at first to a certain extent by accident, that an addition of silicon to the finished metal in the furnace prevented, or very largely controlled, the formation of blowholes in steel ingots or other castings. This led to a careful review and combination of results obtained at different times in the

prosecution of such work, and thus has been developed, by great pains-taking and experiment and with laborious study, the general current practice of mixing with the finished metal a silicide of manganese or a ferro-silicon containing these elements in quantity substantially as shown below:

	Per cent.
Silicon	12
Manganese	20
Iron	68
	100

The presence of silicon in the quantity thus assured appears to have the effect, speaking very generally, of increasing the ability of the metal to hold the gases which it contains more completely in solution or combination with it, so that these gases, being thus held, do not become secreted (or liberated from the pores of the metal) during the solidifying and cooling of the ingot or other piece. This method of treatment of the liquid metal is clearly available in the production of masses of all sizes, from those of trifling weight in which the metal solidifies almost on the instant of striking the mold up to those of such mass that they continue in a fluid or pasty state in their interior for considerable spaces of time.

Fluid compression.—It is to these last named heavy masses only, for obvious reasons, that any process of "fluid compression" can be usefully applied, for this, to be effective, must be commenced almost on the instant of the cessation of the flow from the casting ladle and hence before any actual crystallization has taken place in the outer parts of the mass. This process of compression is also available only for pieces of massive outline throughout every part, so that the general rate of solidifying shall be uniform. Actual experience in the use of fluid compression on a really large scale, that is, with heavy masses and with extreme pressures, has been very limited, so that it is difficult to say what results have been reached, or what proportion of the excellence of these apparent results is really due to the compression process itself. It is not long since the utmost which could be said with reference to this process was simply that it could not be known whether more was not due in the evident good quality of the metal to the excellent grades of raw material which had been employed in its manufacture and to the great skill of the furnace treatment. It is certainly safe to say, however, that the results obtained in methods most nearly analogous to this fluid compression in other departments of the manufacture are such as to warrant fully a large degree of confidence in it. It would probably be hard to say why it should not be as reasonable a thing to aim at a control of the first crystallization of the fluid metal, by an intense compression process which can be rigidly held to the end of the pasty state

through which the metal must pass, as to seek with other appliances and processes (subsequent to this first cooling) of heating and hammering to improve its density and hence its molecular structure.

Agitation.—It has been urged for many years by some skillful steel melters that this troublesome evolution of gas from the steel, a part of which is secreted and confined with such hurtful results, can be promoted by agitation of the fluid metal in the ladle up to the instant before casting, and that within an entirely practicable time it can be wholly completed. Thus by the use of a simple mechanical "agitator" or stirring apparatus the metal can be so "quieted" as to leave no room for a call for special treatment of any other kind.

Need of farther advance.—It is a matter of the highest interest and importance that these more perfect methods for the production of a strong metal, in special forms or shapes, such as have been heretofore obtained at large comparative expense by hand processes of forging, should be even more fully advanced. The manufacture of the metal in the open-hearth furnace is of the simplest kind, so far as the mechanical manipulation and heating of the furnace is concerned, and the money cost is reasonable when compared with any of the other forms of metal which could take its place. There appears thus far to be no limit to the application of the metal in these directly-cast forms except the one of handling the dead weight of the masses produced, and the mere mention of a difficulty of this type suggests and eventually secures the remedy.

Chief use of castings.—Probably the most important use made abroad, in any considerable quantity, of castings of medium weight has been in the parts of marine engines, for shafts, cranks, and various pieces of substantial section or outline, and also in the somewhat complicated pieces used as sternposts for large vessels. These kinds of work are the more important in that they must stand the rigid requirements of Lloyd's inspection before the certificate can be granted to the ship in which the parts are to be used. One of the general tests specified thus is that a test piece, properly cut from the casting, shall show a tensile strength of at least 60,000 pounds per square inch, and that a bar $1\frac{1}{4}$ inches square made from the steel shall stand a cold-bending test to an angle of 90° on a radius in the bend of $1\frac{3}{4}$ inches.

In the United States the use of steel castings is extending in important ways and with very favorable results. The texture of the metal is such as to assure the utmost resistance to wear, as in the teeth of gear wheels; while at the same time the strength and ductility may be made such that it shall endure perfectly the intense vibration and the heavy shocks to which such parts are often constantly subject.

Cooling.—The molding and cooling of the pieces present some difficulties quite apart from the character of the metal as fixed by the melter's treatment. The trouble of an unequal cooling, so constantly met with in the production of iron castings, is aggravated in work-

ing in steel, as the metal becomes solid at a much higher temperature, and in its complete cooling is extremely liable to an internal stress which may tear apart the outline of the casting.

Annealing.—Some makers of the heavier forms of these castings hold that a difficulty not unlike this is liable to be met with in the annealing processes sometimes adopted for the relief and relaxation of these internal disturbances. They believe that the chance of unequal heating in the heavier and lighter parts of a casting may lead to as hurtful results in the development of rents and cracks as the supposed imperfect original cooling. Hence they prefer to make the first cooling the slowest practicable, making the mold of the most friable material possible, so that the contraction of the metal, 2 per cent. or more, shall not be in the least hindered by the resistance of the mold to the needful compression or crushing as the casting shrinks.

STEEL PLATES.

Early practice.—The manufacture of steel plates was attempted during the very earliest practice of the Bessemer process, and with marked success in effecting a relief from the tendency to blister which had been so serious a failing in iron plates. Troubles were encountered continually in the rolling of so compact and hard a metal as the steel was found to be, in the old and comparatively weak mills. After a time it became more fully understood that plates, and the new steel product of that day in general, should be made much softer than was at first supposed. It was known that hard steel was stronger, and it was thought, in the absence at that time of any systematic tests, that as plates for boilers and such uses needed strength they should be made hard. Some of the pioneers realized this fact, and, having acted upon it in their manufacture of plate ingots, have thus permitted an unquestioned record, continuous from the first down to the present day, of the use of steel plates in boilers and for other purposes without failure of any kind due to the essential character or quality of the metal.

Present practice in quality.—The casting of plate ingots and the rolling of plates has now reached in this country a degree of advancement which appears likely to halt for a time. It does not seem needful or even practicable to specify additional tests of quality or mechanical structure above those which are now recognized as amply rigid and sufficient. Whether important saving in cost of production can be made by further study and in the use of the great mills now in operation is an open question. The advance most likely to be made in this department of the steel industry is in the designs and appliances of those who consume the plates.

Uniformity.—The importance of uniformity in the making of plate steel is clearly seen in the fact that a cubic inch of the ingot may spread out by the rolling over a surface of 4 square inches in a quarter-

inch plate. Hence any imperfection in the cubic inch may be found extended through the whole of this thin strip in the finished plate, whether it be due to a blowhole or to some particle of sand, or to an imperfect mechanical mixture of the elements of the metal. This is the more important since it can never be known where such an imperfection will come in the working or the use of the finished plate, whether in a corner of some flange, between a rivet hole and the edge of the plate, or close against the fuel in an intensely heated fire-box sheet. So also some risk has always existed of the occurrence of flaws in bars and other similar pieces which are exposed to tension and cannot be so rigidly inspected as plates of comparatively slight thickness. It is at the same time true that the general character of the tests now applied to steel, and which are held to be worthy of present discussion, do not now relate, except to a very limited degree, to the question of the mechanical soundness of the metal, except as it may depend upon the existence of blowholes that may have existed in the ingot and which may or may not have been closed up solid in the working of the metal into its finished state as a bar or plate.

Quality due to furnace methods.—The use of steel in boiler plates began before the adoption to any important extent of the more strictly modern process of making the metal. Crucible steel plates have been largely used, and although as produced by some makers their grade in carbon was for a time kept too high, yet they held the confidence of consumers who could pay the price necessarily charged for them, until equally trustworthy material could be obtained by other means. The fact was recognized, in reference to this class of steel products as well as others, that the essential qualities of the metal are so completely given to it in the actual process of manufacture that every effort should be made to permit the work of a skillful melter to remain unimpaired in this respect. In other words, as soon as it was seen by prudent men that in punching, bending, flanging, and riveting these plates there was danger of impairing or unequally modifying the absolute molecular structure of the metal, then the utmost pains began to be taken to do all these kinds of work, which must be done in the use of the plates, in the most watchful and painstaking ways.

Plate-working machines.—This has led to some extent to the use in plate shops of better classes of machine tools and more accurate methods. It is true that the general standard of workmanship in some of these shops has advanced and better work in any case would have been done. All such improvements in methods, however, serve an important purpose in enabling the man who buys and uses the boiler or other finished plate structure to enjoy the benefit of the labor and study of the steel melter to the fullest possible extent. Thus the more accurate the forming of the parts which are made up into boiler work the less need be the chance of injury to the metal by the sledging of the plates, close

down one upon another, which is sometimes tolerated. So also the use of the more accurate method of multiple drilling in place of the cheaper use of a punch is preferred by many, and insisted upon by those who call for the best work. The differences which have been noted among authorities as to the injury really done to the metal by punching, in the intense hardening of the metal close around the punched hole, are not easy to reconcile. It appears to be agreed that to ream out the hole a trifle larger after it has been punched, thus wholly removing the injured metal, or to anneal the part punched, is a means of remedying the evil; but when the cost of doing this additional work has been fully allowed for it is reasonably certain that those who pay for the cost of doing the work on suitable automatic multiple drills are the gainers thereby. Riveted joints at best are an evil too largely tolerated, in view of the ease of obtaining plates of almost any probable large size.

Important uses of steel plates.—Probably the most important current use of steel plates is found in the building of the gigantic steam boilers needed for the high-speed steamships which have become so common. The high pressures which must be carried in these boilers are fully warranted by the materials employed and the workmanship exhibited. They may most justly be pointed out as good illustrations at once of the need and the actual advance of the art of the steel melter. For the proper forming of these great plates the use of presses for flanging and bending has been common, in which the work is done by gentle means, so that exact outlines are obtained with trifling cost for labor, and with the least conceivable injury to the texture of the metal. Among the best builders the whole subject of riveting steel plates has received careful attention, that is, as to the manner of doing the work of riveting, and quite apart from the question of the proper design of the joint in respect to its strength. The use of machines in drilling the holes after the plates have been put together has rendered it practicable to fit the rivets much more accurately in the holes, into which they must go at best with some looseness. The use of a mild steel for these rivets puts completely into this part of the work a material which, under the intense pressure of the riveting machine, may be made to flow, and which does flow, into the slightest inequalities of the hole and into a proper, close-fitting outline for the head. In the use of these mild and ductile materials, too, the slight yielding which must take place in so complex a structure as a boiler is most amply provided for, the plates and rivets stretching or bulging by trifling amounts until the exact bearing of each surface upon its counterpart has been fully obtained.

GENERAL METHODS AND REQUIREMENTS IN TESTING.

Chemical tests.—The development of the art of the steel-works analytical chemist has kept nearly even pace with that of the manipulation of the metal in the works. From time to time each has seemed to

drift or to be pushed in advance of the other, the chemist first pointing out a step clearly desirable and practicable in the abstract, but yet of such a nature that the technical obstacles in the works have either proved impossible to be overcome or else too costly as measured by selling values of the product at the given moment. So, on the other hand, there have been differences of results in the treatment of metals which to all appearances should have been identical, but which in the present state of the art cannot be fully accounted for upon any supposition as to elementary combinations which appears reasonable. In fact the steel works as a whole, the melting department more especially, may most usefully be considered, and its processes studied, as a gigantic laboratory. The conditions surrounding these operations and the heats at which they must be managed and perfected, if at all, are such that the critical study and care of them must be undertaken on the spot. The measurement and comparison of these results, when once they have been completed, is naturally a work for the more retired laboratory and testing room. Thus the way may be pointed out, and has been many times, for advances of the highest value, but the following of these suggestions and instructions is to be managed only in the smoke and intense heat of the furnace room, where, to the eye of one new to the scene, it would seem absurd to try to trace and follow out delicate indications in the operations, and nearly impossible that any such traces of change should even have an existence.

In the creation of this new department of steel-works chemistry, Americans have been among the very first in respect to the time when their critical labors began and in the actual advance in the art which has been due to their efforts. It has been found practicable in all the laboratories to assign a large part of the lesser detail of the work to assistants, so that the efforts of the leaders in many instances have been freely devoted to the wider and more general subjects of research through the consideration of which the art has thus advanced. Many new methods of laboratory work have been devised, tested, and perfected if found worthy of being adopted for current use. The processes which were standard and had served their purpose well in the infancy of the business have been freely modified or displaced, so that the processes for determining elements now in use, that is, the tools of the laboratory, are as strictly modern and efficient as any parts of the fixtures or the machinery in other departments of the works.

One advantage which has resulted from this general development of the art of the steel-works chemist is the advance to positions of importance in the management of steel works of men who have had an ample technical training in this department. They have thus been able to give such accurate direction to the effort of the melter who controls or does the hand work of the open-hearth furnace, or to the inside manager of the Bessemer converting house, as to secure the very best possible results from the general operation of the works.

Testing machines.—The advance of the whole art of steel melting and of the manufacture of steel in general has been accompanied by the invention and development of the testing machine, if indeed the relation be not a more interdependent one than this. The need of the more exact development of the steel industry called for additional apparatus by which the progress made could be definitely measured in itself day by day and also compared with what had preceded it in other metals. So also the adaptation of the testing machine, and its current manufacture in many different forms, to all the kinds of tests which the nature of the material could suggest or call for have made the way clearer than it could have been by any other possible means to advances which have proved to be of the highest possible value.

The testing machine, in fewest words, is simply a weighing apparatus or "scale," to use the common word, by means of which the absolute strength of a bar or other piece of the metal shall be determined. This is done by weighing the load required to pull the bar or test piece asunder, this load being sustained during the gradual stretching and yielding by the test piece itself. This stress is brought on the test piece either through a combination of screws with nuts which are revolved upon them or by a hydraulic press, depending upon the intensity of the effort which is required to stretch or to break the piece in hand, or upon the limit, whether high or low, of tests for which the machine has been designed. The indications of results are admirably made, in the best forms of apparatus, by the use of automatic mechanism, a pencil record being made on paper showing the absolute strength of the piece, the limit up to which no perceptible stretching occurred, the rate of stretching when it had once begun, and the amount of this yielding up to the instant of rupture. Thus in the clearest way these important facts can be determined and recorded, for test pieces from each heat of metal, as soon as the piece can be hammered or otherwise worked into the proper form for placing in the jaws of the machine. The evidence is thus obtained in the clearest way which shall show whether the changes made between two heats, or even two successive tests of the same heat, either in mixture of metals or in method of treatment, have been useful or not. The utmost care has been devoted to the design of these machines and the highest skill to their construction, so that errors of observation which had existed in the earlier forms have been overcome and the apparatus has been put into such form that entire confidence may be felt in the result of each test. This renders it certain that each set of two tests or any larger group of the same material shall be accurately comparable with each other and shall not be vitiated by some obscure or unsuspected friction or stiffness of parts in the testing machine itself.

The most important part of this general advance in the art of building testing machines has probably been the devising and perfecting the

details of the large machines, upon which stresses both in tension and compression can be exerted and accurately measured up to 300 and even to 500 tons. In these machines it has become possible, as never before, to test full-sized bars, beams, posts, and all similar pieces up to any probable length whatever, under precisely the same circumstances of length, breadth, and thickness, as must attend the use of these pieces in the structure of whatever kind in which they must form a part. For many years it had been supposed by some that the use of a small test piece cut out of a larger bar, or a small model column or beam, would yield in a testing machine of small or medium capacity results which should be accurately proportional to the area of bar actually tested or to the reduced scale of the model column. It was little less than an actual discovery that the advent of the great 200 to 500 ton machines of the present day showed these results of earlier study to be entirely misleading. The chief need of the steel industry at the present moment, in respect to some of these more exact lines of study which it requires, is that means, both financial and critical, should be found for the constant employment of these splendid machines in original research, for which the present advancing though hesitating state of the steel industry so urgently calls.

The range of uses to which steel is put at the present time is so extremely wide, taking the word steel in its most general sense, that no exhaustive discussion of methods or indications in testing can be undertaken within the limits of this paper. Little more can be attempted than to enumerate in general terms some of the directions in which the employment of this higher-grade metal has been a means of relief from the absolute distress which had attended the use of the more crude forms of iron, and also some of the branches of trade in which the use of steel has been comparatively a matter of indifference, the preference for steel or iron turning partly upon the current price and partly upon the preference of the agent or manager to whom the choice or purchase may have been committed. In this same connection brief mention should be made, or attempted, of the variety of tests which are specified or required of the metal in its finished state; that is, in the form of a bar or a forging as delivered from the rolling mill or the hammer.

Rail steel.—For rails, the largest single item of production, the tests required in nearly every case are few and of the simplest character. The color test for carbon is usually made for the guidance of the manager of the works, whether called for by an inspector or not. This color test, in few words, is made by dissolving a sample of the metal in nitric acid and comparing the intensity of the characteristic brown tint of the diluted solution with the color of a similar acid solution made from a sample of steel of a definitely known composition. In some cases a standard tinted solution is made, for reference day by day as a more convenient method.

Determinations are also made of manganese and phosphorus and

other elements, either daily or at such intervals of time as shall insure the correct mixture of the stock on hand in the current manufacture and guard against the possibility of a change or loss of quality in the materials supplied from sources outside of the personal management of the works. To an important extent the variations in the elements manganese and sulphur are judged of or detected by the behavior of the steel in the rolls. How much manganese is really needful to insure good rolling and how much may be safely tolerated above this limit are somewhat uncertain questions. Manganese appears to increase the tenacity of the metal without diminishing its elongation when strained or its power to resist shocks. In other words, it gives hardness to the metal without brittleness. One and a half per cent. appears to be the extreme limit for this element. The judgment of a manager in any given case is almost certain to be based upon some points which appear to him pertinent simply because he knows them minutely or judges of their probability from apparent trifles. To illustrate the fact that important differences may exist in the proportions of those characteristic elements in rail steels which have been found by the conclusive tests of experience to wear well, a table is given of thirteen samples of rail steel, part being American, part English, and part German. Recent experiments have shown that for certain purposes much higher proportions of manganese are allowable.

Typical composition of rail steels.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Carbon	.40	.21	.49	.33	.28	.30	.29
Silicon	.05	.53	.09	.29	.05	.02	.50
Manganese	1.25	.67	.37	.45	.24	.75	.97
Sulphur	.09	.03	.03	.04	.04	.03	.04
Phosphorus	.11	.10	.10	.20	.24	.16	.08

	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.	No. 13.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Carbon	.38	.44	.32	.38	.17	.20
Silicon	.06	.14	.14	.14	.47	.12
Manganese	1.20	.82	.37	.48	.59	.24
Sulphur	.03	.04	.04	.04	.04	.03
Phosphorus	.04	.07	.15	.08	.17	.07

Drop test.—Some years ago a test of the finished metal as contained in the rail itself was required under a heavy falling weight. For this purpose one of the rail crop ends was usually taken and laid on a substantantial block on knife edges 3 feet apart. For some inspectors a weight of 1 ton falling 20 feet was required to be used, while others called for a weight of 3 tons falling 2 feet. It was supposed that the heavier weight falling through the less distance represented more accurately the stress actually brought upon the rail in current service. The enormous increase in the production of the rail mills more than any

other reason led finally to the abandonment of this test. In place of this cold-bending test some inspectors required that a bar should be hammered out from the head part of a crop end, three-fourths inch square and 12 inches long. This bar was required to stand perfectly a cold bend of 90° on a radius of 1½ inches.

Recent simpler tests.—The inspection and testing of rails has been reduced by some purchasers to a simple examination of each rail for flaws or mechanical imperfections of any kind, especially those due to a failure to cut the crop end far enough back to insure a perfectly sound end. It is also important to determine whether the rail is straight and free from kinks and twists, and that it has been correctly drilled, or punched, for the end connections. So far as the chemical tests or determinations are concerned a very large proportion of all the rails made are accepted by purchasers upon the simple understanding that they shall meet the general current requirement of the market as to endurance. The actual breakages in service from causes that could be clearly traced to the manufacturer have been so few that the time guarantee, which has sometimes been required, has never been brought at all prominently into notice.

Careful study and exhaustive discussion have been brought to bear upon the general question of the chemical composition of rails as affecting their resistance to wear; but it is by no means clear that any useful conclusions have yet been reached which command the uniform approval and agreement of many of the men who are interested in the matter. This disagreement as to exact quality, so clearly shown by the figures of the foregoing table, simply illustrates the fact that in rail steel the limits between which variation in nearly all the elements may safely be permitted are really very wide. The sulphur is seen to be the only element in which there is any approach to an agreement between the analyses of the samples quoted.

Upon the general subject of quality, as advised or preferred by consumers of the metal for widely differing purposes, some light may be afforded by a brief discussion of the requirements, real or supposed, which appear to be called for. These apparent needs, as shown by specifications furnished by purchasers, change from time to time, and from an early day down to the present have undergone as a whole an entire transformation. Nor does it appear that there now exists so complete an agreement among consumers of steel as to warrant in the slightest degree the belief that the end of useful study of the subject has been reached. On the contrary the objections of some men who have looked long and anxiously in this direction of the farther use of steel, of its use in works of their own designing, are of so clearly marked a character that they are becoming each day more conservative in their views, even as based upon the actual experience of other men. It should be remembered that all these advancing uses of steel are strictly competitive, or comparative, to a greater or less degree. That is, the metal must be

furnished for use at such an advance upon the price of iron, if any, as shall convince those who expect to purchase that the saving in dead weight or in endurance will fully compensate for the difference in price.

RECENT APPLICATIONS OF STEEL.

Some of the large uses to which steel was applied many years ago have been of such a nature, in the tests which actual experience has brought to bear upon them, that they have been long placed beyond the limit of doubt. Among these, rails stand easily the first, locomotive driving-wheel tires and boiler plates coming next in order. Next to these uses should probably stand the call which has been made for steel in countless ways for miscellaneous small parts of all kinds of machines and construction. Something that shall stand cold bending perfectly, the forming of a thin head under cold pressure, the turning perfectly with fine finish, or the treatment in a drop-forging press, is called for in enormous total quantity. For these purposes the cost of the metal quite completely disappears as a thing of any consequence provided the metal will meet the actual want.

The use of steel in ship plates and frames has passed the experimental state so far as technical considerations are concerned, and it would seem, if the records of insurance companies are to be trusted, as though the use of it, or a strictly equivalent metal, should be made quite compulsory for such work. For better or worse, the line of price as well as of quality in such products is sharply marked, and must be met in too many cases, so that the engineers and builders who may recommend high standards do not always find themselves supported in their efforts.

Bridge work.—In the general series of eye bars and shaped work for bridges, a well-defined expectation has long existed that more would be done in steel, if not everything, at a very early day. Some important things have been done, it is true, and more are doing daily, but the total use of such steel as compared with the entire current production of bridge work has been quite trifling. The tendency is still clearly marked, as it has been for some years, to the farther use of steel as fast as actual trial of the material shall warrant, that is, the well-planned tests of full-sized construction parts, and as compared with actual contract prices of well approved iron structures. The chief element in close discussion of the fitness of the newer forms of steel as adapted to this work is nearly always found to be the original or essential character of the metal. It is simply impossible to give in a few words even a pretense of a summary of the important technical papers and discussions of the recent past upon this subject of steel in bridge work. It must be sufficient for the present purpose to say that bridge engineers are necessarily conservative, and however rigid and watchful their study of the subject in itself and by comparison of other uses of steel, the

way is by no means fully open to any large extensions of the use of steel in this department of engineering construction.

Axles.—The endeavor to bring steel axles into use under locomotives and cars of all kinds early suggested itself, largely because an important call appeared likely to be made for them as a means of saving dead weight and of providing against the breakages in service which were known to exist with iron axles. For some years, however, it did not appear that any advance would be likely to be made in this use of steel; for the earlier attempts, as in so many other things, were based upon the effort to secure strength (and thus the proposed saving in weight) at the sacrifice of ductility. Hence the early steel axles broke freely in service and the use of steel for this purpose was delayed until the more exact requirements of the service had been determined. This has been done somewhat minutely, although in a few cases the other extreme of quality has been called for, the furnishing of so soft a metal that the wear of the journals has proved very rapid and quite fatal to any advance in the use of such grades of steel for this purpose. The medium course is now taken in the rather limited use at present made of steel for axles, and the quality is indicated as a rule by the "drop test," one of which, for freight-car axles, provides that the test axle shall stand without fracture five blows of 20-foot fall of a 1,640-pound weight, striking midway between supports 3 feet apart, the axle being turned over after each blow. The use of steel for this purpose is too often hindered by the consent of railroad managers, sometimes given without careful consideration, to the use of iron axles of such a quality that no steel worthy of the name could be expected to compete with it.

I-beams.—The call has been very limited for these shapes; so slight in fact that little has yet been done in the designing of new outlines for the sections. The preference seems rather to be in favor of retaining the old outlines and increasing the load slightly when the way appears open to do so. Experience seems to show that a soft steel beam, below the ordinary limit of carbon in rails, for example, rolls with less stress upon the machinery than iron. At the same time it is true that considerable amounts of rather low-grade iron find their way into some of these beams, and thus the question of price becomes a trying one as limiting the use of steel in this class of work.

An important limiting point in the use of steel in built work in bridge construction, such parts as are required for posts and top chords, is found in the marked uncertainty of the effect produced by the punching and riveting of those parts which must be thus joined together. These posts, and all similar pieces which serve as compression members, need stiffness as an essential quality; but if the metal supplied for their manufacture is in itself stiff enough to meet this requirement it is likely to be injured in the punching and general fitting needed. Some relief may be found from this chance of injury by the use of drilling machines in the place of punches for the holes, although this must lead to an in-

crease of cost in the finished work. Careful study is still given, in the increase of the manufacture of the milder grades of the metal for these purposes, to the possibility elsewhere referred to in this paper, of developing more fully this extremely desirable element of stiffness without involving a degree of brittleness such as shall be dangerous.

By the use of ingots cast roughly to outline the rolling of beams is somewhat simplified, and the greater certainty above iron of rolling perfectly sound bars of great length aids in the reduction of cost to the manufacturer and in the convenience of use of the bars for some purposes in which long single pieces are desirable.

Shafting.—This constitutes an important fraction of the whole product of bars of medium and heavier weight in iron and naturally an outlet has been sought in this direction for steel. It does not appear, however, that more than 6 or 8 per cent. of the whole production of shafting has been made of steel, as indicated in current orders at the present day. The need in this case is for a metal which shall resist twisting and shall take a good polish on the journal surfaces. The resistance to bending has been most usefully provided for by putting up the hangers at very frequent intervals, so that little remains upon which to base a choice, except the cost price to the purchaser. The selection is still farther narrowed in favor of steel by the well-established fact that such metal as is suitable for shafting can be turned and finished more cheaply than iron, although the high quality of ductility in steel is of less importance in shafting than in some other kinds of bars upon which some supplementary forging must often be done.

Nail plate.—The latest important advance in the use of rolled forms of steel is undoubtedly found in the commencement of the manufacture by the Bessemer process, in large quantity, of nail-plate blooms or slabs. This advance includes also the development of the possibility of cutting the nails without important changes of any kind on the machines from a quality of steel which shall clearly meet the requirements of the market in respect to stiffness. As the quantity of nails consumed each year in this country is upwards of 300,000 tons, it is clear that any important change of the raw material of this industry must affect large numbers of men and must call for considerable expenditures of money in providing a new plant and also the laying off and possible destruction of important items of the older furnaces and fixtures.

The manufacture appears to have advanced far enough with the new plant and fixtures to show conclusively that the anticipations of those concerned are likely to be realized in the relief experienced from many troublesome complications which had existed under the older order of things. The cost of the new qualities of slabs may be subject to more mature development, but some little savings are noted, such that in the aggregate they may prove to be important items in the case. These are the saving of waste in heating, due to the lower temperature called for in the rolling of the plates, the saving in the time, and

the double saving of fuel, due both to the reduction of temperature and of time. The smoother edges of the plates made of steel also count favorably. The very careful watching of the production of a converter when worked up into this form very clearly shows a degree of uniformity of texture in every way commendable and fully equal to that of the best boiler plate.

In the use of steel after it has left the rolling mill or forge as a finished plate or bar much yet remains to be learned. In many cases it has been an absolute misfortune, however unavoidable, that it has been given up to workmen who have always been used to working iron, and in whose hands the finest material has more than once undergone speedy condemnation. Leading men among consumers of steel do not always recognize the fact that steel, although derived from iron ore, is quite another metal from iron, using these words in their commercial sense rather than a technical one; and as such might reasonably be expected to require different methods of treatment. An endless series of illustrations of the truth of these statements could be given, each tending to show that a very large fraction of the defects which are reported in steel, as delivered from the mill and as failing in the hands of the workman, is simply due to the protest which the metal itself makes against the methods pursued in its later manufacture. Some of the parties interested have appreciated the peculiarities of the metal after they have been shown, by quiet explanation and the simplest tests, where the truth lies. No doubt some failures in working and in use have occurred through an absolute lack of any proper quality, but more by far have been recorded as the result of efforts to presume upon the characteristic properties of a metal which may have been set forth to some workman as better than iron, but who does not realize that it may need to be handled more carefully if its good qualities are to be preserved or even to be exhibited at all. There can be no doubt that the chief complaint, a lack of uniformity, has been very largely due to a difficulty on the part of the user of the metal in realizing that he has worked the parts of the metal in different ways, even though this difference may have been so slight as to have escaped his attention.

COST OF PRODUCTION.

Statements relating to any of these processes which are given in sufficient minuteness of detail to be really useful in any way, are difficult to obtain. Methods of keeping such accounts differ widely, so that it is rare that any two statements can be usefully compared without an important amount of guesswork in the rearranging of the items, which must impair the exact comparative value they might otherwise possess. At some works the details of cost are kept separately and classified upon the basis of a general schedule for the various departments, so that any undue excess cf cost which may be discovered

or suspected can be traced with the utmost certainty to its source and the needful remedy applied. It is quite obvious that the skill and pains-taking character of the management of a works cannot appear on the face of any cost statement, however carefully it may be made up, for circumstances often differ extremely at one works from those which may prevail at another, however closely these works may seem to resemble each other. The most cautious efforts of management, amounting even to sacrifice, may fail in maintaining a profit in the conduct of a works, however favorable the location and general circumstances may appear to be.

The important reduction in the quantity of the softer grades produced must always act as a tendency toward an increase in cost in the use of the Bessemer process or until a more extended experience has been acquired. The constant watchfulness needed to hold the metal within the recognized limit of quality, whatever may be fixed as that limit, must serve to check rapidity of operation. The frequent changing of carbon grades or of other proportions of elements needed to fill exact orders, and the checking of work at the rolls due to changes in sizes of blooms to be rolled or to be cut at the shear, both tend to that increase of cost which in so many cases is urged against the purchase of the metal after all other needful requirements may have been filled. In few things at all of its kind is the reduction in cost which is due to an increase in the output of the furnaces so marked and so large in actual amount as in the production of steel. All the furnace plant must be kept at nearly or quite full heat, if anything at all is done, whether the product be little or much, and, as a rule the full staff of men must be kept on.

In the approximate and quite recent statement of cost of rails which is given herewith the items are noted in the ratio each bears to the total in the division to which it belongs. It may thus be ascertained what the cost of each item is, upon the basis of any assumed or known cost of the finished rail or of the rough ingot. Thus it will be seen that blooms heavy enough to make a ton of rails will cost $32.25 if the finished rail is known to cost $36 per ton. So also it may be seen that the cost of fuel in making blooms is about 61 cents if the finished rail is $36.

Statement of ratio of items in steel rail-making operations.

Items.	Ingots.	Blooms.	Rails.
Material	.897	.935	.896
Fuel	.019	.009	.011
Refractories	.012	.001	.001
Labor	.044	.027	.060
Repairs	.016	.017	.020
Office expenses, etc	.004	.007	.008
Incidental	.008	.004	.004
	1.000	1.000	1.000

INDEX.

NOTICE.

The bulletins of the United States Geological Survey are numbered in a continuous series and will be bound in volumes of convenient size.

This bulletin will be included in Volume IV.